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Geology of the Walnut Wells Quadrangle, Hidalgo County, New Mexico

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Abstract

The Walnut Wells 15-minute quadrangle in southern Hidalgo County, New Mexico, lies in the Basin and Range physiographic province and includes a part of the Animas Mountains. Strongly deformed Paleozoic and Cretaceous sedimentary rocks are overlain unconformably by a less deformed thick series of Tertiary rocks. Late elevation of the Animas range was relatively small so that erosion has not proceeded deep enough to expose pre-Tertiary rocks and structures except in one area. Tertiary arching in the east-central part of the quadrangle resulted in exposure of older rocks and structures.

Late Paleozoic formations exposed include Horquilla Limestone, Earp Formation, Colina Limestone, and Concha Limestone, all of which are similar in character to the corresponding formations in the Big Hatchet Mountains fifteen miles to the east. The Early Cretaceous Hell-to-Finish, U-Bar, and Mojado Formations described from the Big Hatchet Mountains area are recognized in this quadrangle. A new Cretaceous conglomerate formation, which overlies the Mojado, is named Cowboy Spring Formation.

Layered Tertiary rocks consist largely of quartz latite tuffs but also include rhyolfte tuff, latite and andesite flows, conglomerate beds, and fine-grained sedimentary beds. Many of the volcanic formations are welded tuffs. In the northern part of the area the Animas stock intruded the Oak Creek Tuff. The fact that these two rock masses were derived from a common magma which ascended through a common channel is indicated by field evidence, similarity in mineral and chemical composition of the intrusive and extrusive rocks, and similarity of elongation of zircon crystals in the rocks of the two masses. The monzonite porphyry of the Walnut Wells plug south of the Animas stock has zircon elongations similar to those found in the Animas Quartz Monzonite and the Oak Creek Tuff. This fact suggests origin from the same magma for all three rock masses. The zircons of other extrusive formations in the quadrangle have dissimilar elongations.

Several volcanic centers or source areas are present in the quadrangle. Besides the channels occupied by the Animas stock and Walnut Wells plug, the source areas of the Basin Creek Tuff and the Pine Canyon Formation are known; the source of the Center Peak Latite was probably from the area of its greatest thickness.

The Winkler anticline, which is doubly plunging and northeast-trending, is one of the most instructive structures of southwestern New Mexico. It started to develop before deposition of the Lower Cretaceous rocks. Development continued during Cretaceous deposition, reached a maximum during the time between deposition of the Cretaceous and Tertiary formations in the area, and continued during Tertiary deposi-

tion. Two significant points are demonstrated by the structure; first, that the region was influenced by an early period of deformation (probably post-Permian—pre-Cretaceous) and second, that this old structure continued to develop intermittently during Cretaceous and Tertiary deposition.

Geologic structures include tight and open folds, high-angle faults trending in various directions, a lineament which is the locus of two intersecting unconformities, and normal faults. Evidence of four periods of deformation is found in the area. The first period, in which growth of the Winkler anticline began, is mentioned above. The second period, which was later than Early Cretaceous deposition and earlier than Tertiary deposition, included the strongest deformation. The third period, which occurred during Tertiary deposition, included mild deformation which is recorded chiefly in depositional features of Tertiary rocks. The last period, which was after Tertiary deposition, may have been a continuation of the period of Tertiary deformation. During this last period, which is still somewhat active, broad gentle folds were formed, and the Animas Mountains were elevated and tilted eastward along flanking normal faults.

Mineral deposits of the quadrangle include manganese, silver, lead, and fluorspar. Silver and lead were mined commercially from the Gillespie and Red Hill mines many years ago; only manganese has been produced commercially in recent years.

Introduction

The Walnut Wells quadrangle is located in Hidalgo County in southwestern New Mexico approximately 50 miles south of Lordsburg and 30 miles southwest of Hachita. It is a 15-minute quadrangle having an area of about 250 square miles and is bounded by the following geographic coordinates: lat. 31°30' N.—lat. 31°45' N., and long. 108°30' W. —long. 108°45' W.

The area may be reached by traveling southwest of Hachita on New Mexico Highway 81 and continuing west from the highway on roads leading to the Young Ranch and the Timberlake Ranch. These are graded dirt roads that are passable at all times. Other ranch roads in the quadrangle should not be traveled without inquiring about road conditions.

Most of the quadrangle lies in the Animas Mountains. The eastern part extends into Playas Valley and the northwestern corner includes a small part of Animas Valley. The geographic setting of the quadrangle is shown in Figure 1. The oblique aerial photograph of Figure 2 shows much of the quadrangle.

The region is arid with an average annual precipitation of about 10 inches. Thunderstorms common during the late summer account for most of the annual precipitation. Winter weather is mild with only brief periods of below-freezing temperatures and light snowfalls. During the summer, daytime temperatures often exceed 100°, but the nights are cool.

Vegetation and wildlife are those typical of southwestern New Mexico. Valleys have some areas of grass, but mesquite and creosote bush are predominant. The mountains have scattered juniper at the lower elevations, juniper, oak, and pinion pine at intermediate elevations, and yellow pine, fir, and oak at higher elevations. High peaks in the southwestern part of the quadrangle have thick, nearly impregnable growths of oak and manzanita chaparral. Sycamore, cottonwood, black walnut, live oak, wild grape, and many other trees and shrubs are common on the canyon floors, many of which have flowing streams in late summer and fall. Various cacti are abundant, especially throughout the hills and mountains. Many types of shrubs and grasses supply food for game animals and livestock.

The common larger wild animals found in the area include whitetail deer, mule deer, black bear, kit fox, coyote, javelina, wildcat, and mountain lion. Pronghorn "antelope" are found on the flats in the extreme southern part.

The chief industry of the area is cattle ranching. The quadrangle includes all of the Young Ranch and parts of the Timberlake, Diamond A, Godfrey, Bessie Adams, and Monroe Dunagan Ranches. In Playas Valley several small irrigated farms produce chiefly cotton and cattle

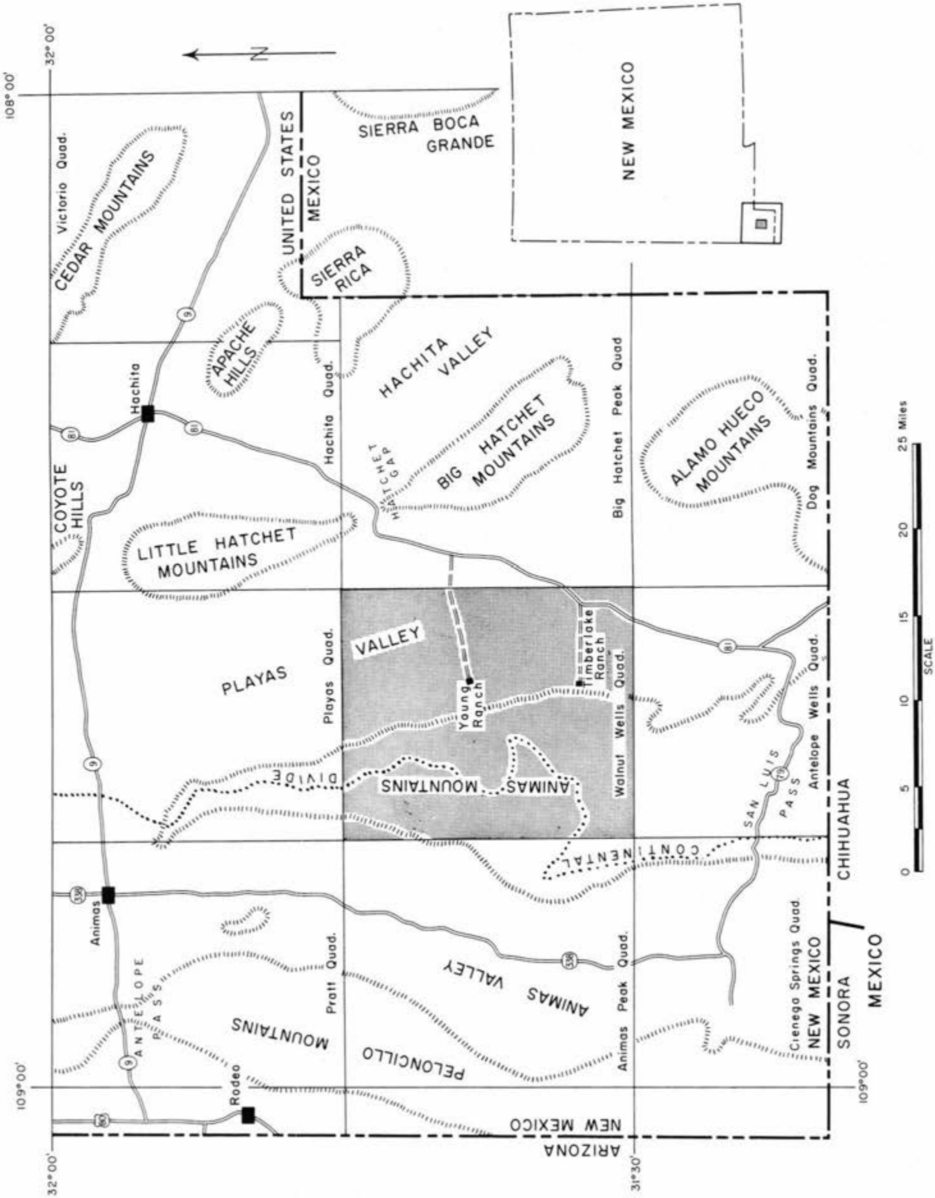

Figure 1
INDEX MAP OF THE WALNUT WELLS QUADRANGLE

Figure 2

WESTWARD VIEW OF THE WALNUT WELLS QUADRANGLE

The prominent Animas Mountains are in the middle of the photo; Playas Valley is in the foreground, and Animas Valley is in the background. The high forested part of the Animas Mountains is dominated by 8,500-foot Animas Peak, which here has a light cover of snow. Cowboy Rim escarpment flanks the east side of the range left of the center; Gillespie Mountain is right of the center. (Air photo by Zeller) feed. In past times lead and silver were produced from the Gillespie mine and the Red Hill mine, but in recent years the only mining activity has been the sporadic working of a small manganese mine. Recently, petroleum companies have become interested in the area and have conducted stratigraphic, reconnaissance geologic, and geophysical surveys. The population of the quadrangle is less than 30.

The quadrangle lies in the Mexican Highland part of the Basin and Range physiographic province, which is characterized by generally north-south trending dissected fault block mountains separated by alluvial valleys. The Animas Mountains, which traverse the quadrangle, extend northward into the Pyramid Mountains; southward they split into two ranges and pass into the Sierra Madre Occidental in Mexico.

The Continental Divide follows the crest of the range through the quadrangle and separates the Animas Valley drainage from the Playas Valley drainage. The Animas Valley drains northward into a playa west of Lordsburg in the Gila River drainage. The portion of the Playas Valley included in the quadrangle drains northeastward through Hatchet Gap, and then southeastward into Moscos Playa in Mexico. Should Moscos Playa overflow, it would drain into a series of playas, which would drain into the Rio Concho, a tributary of the Rio Grande.

In this region a thick section of pre-Tertiary sedimentary rocks was strongly deformed during early periods of orogeny. After erosion, these earlier rocks and structures were covered by a thick blanket of Tertiary volcanic rocks. Subsequent deformation, uplift, and erosional dissection of the Animas Mountain fault block produced the present topography.

Because elevation of the Animas Mountain block was not great compared to that of the Big Hatchet and other mountain blocks, erosion has not proceeded deeply into the geologic column; thus, pre-Tertiary rocks are exposed in less than 10 percent of the bedrock area. Paleozoic and Cretaceous rocks are exposed only in the area south and southeast of Gillespie Mountain, where Tertiary arching made possible deeper erosion into the stratigraphic succession.

Differential erosion of many rock types has produced a variety of topographic features. In areas of gently dipping successions of alternate hard and soft volcanic rocks, cliffs and terraces are common; some cliffs may be followed for miles. The Park, a high grassy area of subdued relief limited on two sides by Cowboy Rim, was produced by the erosion of a soft formation that rests upon a resistant one (fig. 3). Elevations range from 4300 feet to 7309 feet. Elevation differences of 1000 feet in less than half a mile are common.

PRIOR WORK

No detailed geologic mapping was done in this quadrangle prior to the present investigation. Darton (1922, p. 275) stated that there are

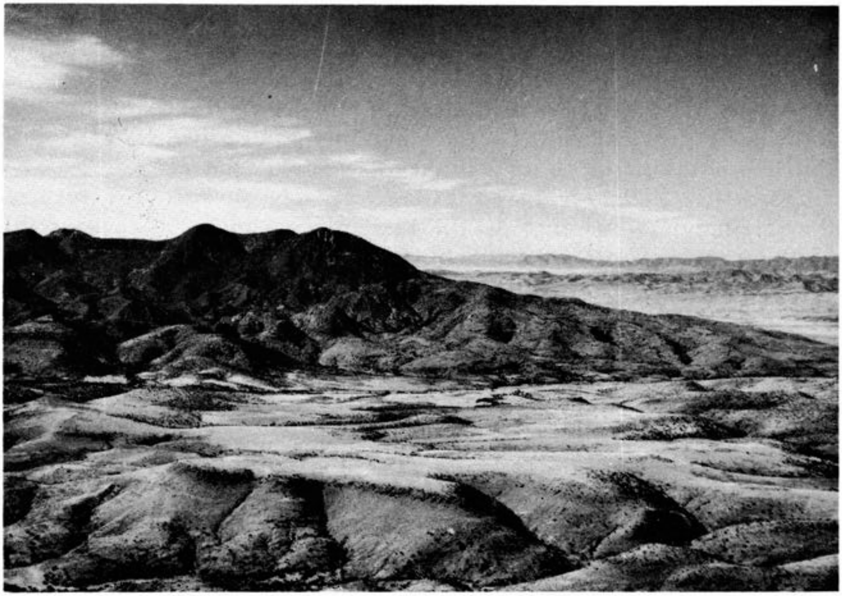

Figure 3

WESTWARD VIEW OF THE PARK AND ANIMAS PEAK

The Park is a small plateau produced by erosional stripping of soft OK Bar Conglomerate from more resistant Park Tuff. Double Adobe Creek drains to the right from the far side of the Park. (Photo by Zeller)

Tertiary igneous rocks and an irregular dome of rocks of Comanche age faulted on several sides. On the geologic map of New Mexico Darton (1928a) mapped the portion of the Animas Mountains that lies in the quadrangle as undifferentiated Tertiary volcanics with an inlier of Cretaceous rocks south of Gillespie Mountain. Darton (1928b, p. 348) also wrote, "In no part of these mountains have details of structure been determined."

Schwennesen (1918) studied the groundwater of the region; some of his remarks are pertinent to the Walnut Wells quadrangle.

PRESENT WORK

The present work on the Walnut Wells quadrangle was started by Allen M. Alper in 1954. He mapped approximately the northern two-thirds of the quadrangle and spent some 245 days in the field. He was assisted by his brother, Jay T. Alper, during the summers of 1954 and 1955 and by the late Trinky Lopez during the fall of 1955. His work was conducted under the auspices of the New Mexico Bureau of Mines and

Mineral Resources and Columbia University, and it was financed by the Bureau, a grant from Kent Memorial Fund of Columbia University (summer of 1954), and scholarships and a fellowship from Columbia University. Alper and Poldervaart (1957) published the results of their study of the zircon petrology of the quadrangle, and Alper (1957) wrote a Ph.D. dissertation on his study in the quadrangle.

Robert A. Zeller, Jr. mapped approximately the southern third of the quadrangle, which includes the Timberlake Ranch. He spent a total of about seven months in the field between 1956 and 1963. He was assisted during part of this time by Rosalio Cobos. Part of the work was financed by the New Mexico Bureau of Mines and Mineral Resources, and the remainder by himself.

After completion of the mapping, field checking disclosed certain areas in which the geology needed further clarification. Zeller restudied some of these areas. Regrettably, due to insufficient financial support, it was not possible to study them in detail. Portions of the map and text where data are lacking or insufficient are indicated.

Areas mapped geologically by each author are shown on Plate 1. Each author studied and described the Tertiary formations confined to the areas in which he mapped, and both authors contributed to the study and descriptions of those Tertiary formations that are common to the areas studied by both. All laboratory studies, including petrographic descriptions, computation of C.I.P.W. norms, computation of differentiation indices, and studies of zircon petrology, were made by Alper. He studied the intrusive bodies and worked out their relationships to extrusive masses. Alper studied the manganese deposits of the quadrangle; most of the information on the Red Hill and Gillespite mines and on the fluorite prospects was assembled by Zeller. The Paleozoic and Cretaceous formations were described by Zeller chiefly from his field observations; two stratigraphic sections measured by Alper are included. Zeller worked out the structure of the Winkler anticline and the hypothesis of the Deer Creek lineament, and from the structures mapped and studied by Alper and himself, he interpreted and described the periods of deformation that influenced the area.

Areal mapping of most of the quadrangle was done on U.S. Soil Conservation Service aerial photographs on a scale of about 3 inches equals 1 mile, and the data were transferred to the topographic map of the Walnut Wells quadrangle (pl. 1). During final stages of the work, Zeller remapped the area between Bennett and Gillespie Creeks, the area east of Cowboy Spring, and the area west of the headwaters of Double Adobe and Deer Creeks; remapping of the latter area was done on the topographic base map because aerial photographs were not available.

ACKNOWLEDGMENTS

The writers are grateful to the New Mexico Bureau of Mines and Mineral Resources and Columbia University for partially sponsoring this work. They are particularly grateful to Eugene Callaghan, who was the director of the Bureau during most of the project, and to Charles H. Behre, Jr., professor of geology at Columbia University.

In addition, Alper gratefully acknowledges the following persons for their help: Professor Arie Poldervaart of Columbia University and Professor Arnold J. Silverman of the Montana State University for much laboratory advice; Professor John Imbrie of Columbia University for advice on statistical methods; Jay T. Alper and Trinky Lopez for serving as field assistants; Anthony Gentile for taking geological photographs; and John H. Schilling for his help in the discussion of the mineral deposits. Field data were discussed with members of the New Mexico Bureau of Mines and Mineral Resources, notably W. E. Elston, H. L. Jicha, F. J. Kuellmer, and F. E. Kottlowski. He also deeply thanks some of the ranchers of the area, especially Mr. and Mrs. Herbert Young and family, and Mr. and Mrs. George Godfrey, who helped make his work most enjoyable by their kindness and hospitality.

Zeller acknowledges the New Mexico Bureau of Mines and Mineral Resources for the financial aid that helped to make the completion of this project possible. He sincerely thanks Robert Timberlake, owner of the Timberlake Ranch, for his complete cooperation, and for his generosity in furnishing, without charge, fine horses, quarters, and many meals. He is indebted to the Herbert Young family for their hospitality and aid. The kindness of Rosalio Cobos in assisting with the field work without pay is deeply appreciated.

The following paleontologists are sincerely thanked for their identification of fossils critical to the dating and correlation of Paleozoic and Cretaceous formations: Charles B. Read, W. A. Cobban, Helen Duncan, and Ellis L. Yochelson, all of the U.S. Geological Survey; and Garner L. Wilde of Humble Oil & Refining Company.

Mr. J. F. Fitch of Hachita and Mr. Carl F. Schaber of Deming are acknowledged for their kindness in making available information on the Red Hill mine.

The writers are grateful to Max E. Willard, State Bureau of Mines and Mineral Resources, for critical reading of the manuscript. The kindness of Mr. and Mrs. Harry L. Baldwin, who edited the English of the report, is sincerely appreciated.

Pre-Tertiary Rocks

Exposures of pre-Tertiary rocks are limited to an area south of Gillespie Mountain that extends from the headwaters of Gillespie and Bennett Creeks eastward to the vicinity of the Young Ranch and southward beyond Cowboy Spring. This area is the site of the Winkler anticline, which started developing prior to Cretaceous deposition and had several periods of further development, the latest of which caused arching of Tertiary rocks. Tertiary arching in this area enabled erosion to cut deeper into the stratigraphic succession producing the inlier. The resulting exposures are of upper Paleozoic and Cretaceous sedimentary formations.

PENNSYLVANIAN AND PERMIAN SYSTEMS

Throughout the region the normal succession of upper Paleozoic formations in ascending order is Horquilla Limestone, Earp Formation, Colina Limestone, Epitaph Dolomite, Scherrer Formation, and Concha Limestone. The Horquilla, Earp, and Colina are exposed on the Winkler anticline. Concha Limestone is exposed east of the Young Ranch in an elevated fault block. Though the Epitaph Dolomite and Scherrer Formation are not exposed, the evidence shows that they are present in the area and were exposed prior to Tertiary deposition.

Because these formations were recognized only during the final stages of the project, and because sufficient funds were not available, they were not studied in detail and are described only briefly. Descriptions of these formations in the Big Hatchet Mountains (Zeller, 1965) are applicable in general to this area.

HORQUILLA LIMESTONE

Horquilla Limestone is exposed at the core of Winkler anticline on the high ridge south of Gillespie Creek. The formation was not measured, but several hundred feet of the upper part are exposed. The Horquilla consists of medium-bedded and massive limestone that weathers pale bluish-gray, varies from light gray to nearly black on fresh fracture, has a medium- to fine-grained clastic texture, contains various fusulinids, and includes chert nodules ranging in color from white through shades of gray to black. Large areas of the limestone are silicified along faults and fractures.

In the Big Hatchet Mountains the Horquilla is about 3600 feet thick; the lower 2100 feet is Pennsylvanian and the remainder is Wolf-camp (early Permian) age. Only the upper part of the Wolfcamp portion is exposed in the Winkler anticline.

The formation was first recognized in the area by the senior author through his identification of *Schwagerina* sp. and *Pseudoschwagerina* sp., fusulinids that characterize the upper Horquilla. Features that serve to distinguish the formation from others in the area are the obvious bioclastic texture, the massiveness of many beds, the thick sequence of limestone, and the abundance of fusulinids.

EARP FORMATION

A nearly continuous elliptical-shaped exposure of Earp Formation, which lies disconformably upon the Horquilla Limestone, surrounds the exposure of Horquilla Limestone on the Winkler anticline. Here it has the same general characteristics as in the Big Hatchet Mountains; brown-weathered thinly crosslaminated beds of calcareous siltstone are interbedded with soft beds of unconsolidated light gray and brown clay and shale. No fossils are found except for poorly preserved plant material. The formation may be identified by its lithology and its stratigraphic position between the Horquilla Limestone and the Colina Limestone. The lower 612 feet of the Earp Formation is described in the Gillespie Creek stratigraphic section (appendix). A thicker, well exposed section of the formation is present in the SW1/4 NE1/4 sec. 3, T. 31 S., R. 18 W.

COLINA LIMESTONE

A broken ring of Colina Limestone surrounds the Earp Formation on the Winkler anticline. Only the lower part of the Colina Limestone is preserved; the upper part was removed by pre-Cretaceous erosion. Along the eastern end of the anticline the Colina Limestone is missing, and basal Cretaceous beds rest upon the Earp Formation.

Identification of the Colina Limestone is difficult; the Colina may be confused with certain of the Cretaceous limestones that are deficient in fossils. In the Walnut Wells quadrangle the Colina has the same lithology as it has in the Big Hatchet Mountains. It is a medium-bedded limestone that is dark gray or black on fresh surfaces, medium gray on smoothly weathered surfaces, and very finely crystalline; a few thin beds of buff-weathered dolomite having knots of silica are present in places. Chert nodules are rare. Echinoid spines and thorny productid brachiopods are present in a few strata.

Fossils are rare, but enough silicified fossils were found to be certain of the formation's identity. To confirm the age of the formation, the senior author collected fossils which, through the courtesy of Charles B. Read, were sent to the U.S. Geological Survey for study. Ellis L. Yochelson identified them and consulted with Helen Duncan on the corals and bryozoans. Concerning the age of the fauna, he comments as follows (written communication, 1959): "It is Early Permian in age, and in that sense, correlation to the Colina Limestone is warranted. The presence of *Omphalotrochus* suggests a Wolfcamp age. A detailed study of the cephalopods might confirm this age."

Yochelson's faunal list is as follows:

Sponge, undetermined
Plerophyllid coral, young (Helen Duncan ident.)
Echinoid plate and ? spines, indet.
Crinoid stems, indet.
Septopora sp. (Helen Duncan ident.)
**Reticulatia* cf. *R. huecoensis* (R. E. King)
"*Marginifera*" sp.
Composita? sp.
Wellerella sp.
Euomphalid gastropod, indet.
**Omphalotrochus* sp., indet.
Plagioglypta? sp.
Aviculopinna sp.
Straight and coiled nautiloids, undetermined
Ammonoids, undetermined

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* significant for age determination

This collection is retained by the U.S. Geological Survey and was given U.S.G.S. No. 18467-PC.

EPITAPH DOLOMITE AND SCHERRER FORMATION

The Epitaph Dolomite and Scherrer Formation are not exposed at present in the Walnut Wells quadrangle. They were removed by pre-Cretaceous erosion from the axial portion of the Winkler anticline.

However, rocks of the Epitaph-Scherrer-Concha sequence were exposed near the headwaters of Millsite Creek during early Tertiary deposition. This is indicated by a bed of conglomerate composed of Epitaph Dolomite and Concha Limestone boulders in the lower part of the Tertiary Oak Creek Tuff. The dolomite is identified as Epitaph because it contains knots of silica, a distinctive feature of the Epitaph Dolomite throughout the region. The limestone is identified as Concha because it contains an abundance of chert nodules and silicified robust productid brachiopods. Many boulders are as large as 20 feet in diameter; one is about 100 feet by 50 feet. Such large boulders indicate a nearby source.

The Scherrer, which lies between the Epitaph and Concha, is only a few feet thick in the region. Though no detritus derived from the Scherrer was noted in the conglomerate, the formation was undoubtedly exposed with the Epitaph and Concha during early Tertiary time.

CONCHA LIMESTONE

An isolated and prominent hill one mile east of the Young Ranch consists of Concha Limestone. An apparently high angle fault on the southwest side of the hill elevated the block containing the Concha.

About 200 feet of the formation is exposed; bedding is relatively undisturbed except for a gentle southwestern dip. The rock consists mostly of limestone, light-gray on both fresh and weathered surfaces, medium crystalline, clastic, and medium-bedded; many beds are rich in chert nodules and in fossils replaced with chert. A few beds are of dolomite, which weathers light brownish gray and contains fossils silicified by white chert.

This formation is recognized as the Concha Limestone because of the following features diagnostic of the formation in the Big Hatchet Mountains (Zeller, 1965): the presence of *Parafusulina* sp., the abundance of silicified robust productid brachiopods, and the similarity of the lithology. Garner L. Wilde confirmed the identification of *Parafusulina* sp. Of this fossil Wilde states (written communication, 1959), "This form is identical with the one from about 400 feet above the Scherrer Quartzite [in the Big Hatchet Mountains]; or about a third of the way up in the Concha Formation, and is clearly of Leonardian age."

CRETACEOUS SYSTEM

The base of the Cretaceous section, exposed only near Winkler anticline, rests with erosional unconformity upon the Earp Formation and Colina Limestone. The upper part of the Cretaceous section is truncated by an angular unconformity upon which Tertiary rocks lie.

The exposed Cretaceous rocks are lithologically divisible into four formations. The lowest, the Hell-to-Finish Formation, consists of red arkose and shale; the next one, principally a limestone, is identified as the U-Bar Formation; the overlying sandstone is identified as the Mojado Formation. These three formations were named and described in the Big Hatchet Mountains area (Zeller, 1965). A conglomerate formation resting conformably upon the Mojado cannot be correlated at present with any formation in the region and is therefore given a new name, Cowboy Spring Formation.

The U-Bar and Mojado Formations are of Early Cretaceous age. The U-Bar is probably Trinity and Fredericksburg (?) here as in the type area, and the Mojado is Fredericksburg and Washita. The Hell-to-Finish Formation is undoubtedly Early Cretaceous. The Cowboy Spring Formation is latest Early Cretaceous or earliest Late Cretaceous.

HELL-TO-FINISH FORMATION

The Hell-to-Finish Formation is exposed in the area of the Winkler anticline and rests upon the irregular pre-Cretaceous erosion surface. In places it lies upon a thin remnant of the Colina Limestone; on the eastern nose of the anticline it rests upon the upper and middle Earp Formation. Here 769 feet of the formation was measured in the Gillespie Creek stratigraphic section, which is described in the appendix. Red beds of the Hell-to-Finish overlie the similar lithology of the Earp, but the contact may be chosen with little difficulty because of the limestone boulder and cobble conglomerate at the base of the Hell-toFinish beds. The bulk of the formation consists of red and green shale interbedded with red and brown arkose and arkosic sandstone. The only fossils noted are of wood.

On other parts of the anticline the Hell-to-Finish Formation has a similar lithology but is only a few tens of feet thick and usually is concealed. Such an abrupt change in thickness of the formation is due to deposition upon a highly irregular surface. Because the formation is so thin, it is included with the U-Bar Formation for geologic mapping in this area.

The age of the Hell-to-Finish Formation is presumed to be Early Cretaceous because the lithology of this formation is transitional upward with that of the U-Bar Formation of Early Cretaceous age.

U-BAR FORMATION

Identification of the U-Bar Formation in the Walnut Wells quadrangle is based upon several similarities with the type U-Bar. The formation is overlain conformably by a sandstone unit that is established as the Mojado Formation on strong paleontologic evidence. Lithologic similarity of this formation with the type U-Bar is striking; the rock is predominantly of limestone, and most of the gross lithologic units or members of the type U-Bar are recognized here. Although the fauna of the formation in the Walnut Wells quadrangle was not studied by specialists, the fossils and the succession of faunas are similar in aspect to those of the type formation.

The U-Bar Formation is best exposed between Gillespie and Bennett Creeks where the rocks are folded in the Winkler anticline. A faulted band of exposed U-Bar Formation encircles the core of Paleozoic exposures and is circled by exposures of the overlying Mojado Formation. Another exposure of the U-Bar lies half a mile south of the Young Ranch where it is tightly folded and contorted. The formation rests conformably upon the Hell-to-Finish Formation, which in places is only a few tens of feet thick and is usually concealed. The upper conformable contact of the U-Bar is well exposed in several places on the Winkler anticline. The Gillespie Creek stratigraphic section, which includes the U-Bar Formation, is shown in the appendix.

Comparison of the U-Bar Formation of the Walnut Wells quadrangle with the type formation based upon field observations by the senior author shows important similarities and differences. In the type area the U-Bar is divided, in ascending order, into brown limestone member, oyster limestone member, limestone-shale member, reef limestone member, and suprareef limestone member. Though such members can hardly be expected to extend over great areas, all but the brown limestone and limestone-shale members are present in the Walnut Wells quadrangle.

Most of the U-Bar Formation in the quadrangle consists of fossiliferous bioclastic limestone interbedded with brown-weathered sandstone and shale. Oysters and many other fossils are common. Sandstone beds are so numerous in some parts that in areas where the rock succession is obscured these parts can be distinguished from sandstone of the Mojado Formation only by the presence of thin, oyster limestone beds. With the exception of the greater quantity of sandstone, the lower part of the formation resembles the oyster limestone member of the type U-Bar Formation.

In the type U-Bar the oyster limestone member is overlain by the limestone-shale member consisting of a rhythmic succession of thin beds of dense smooth-textured limestone and thicker beds of gray and brown shale. This member is missing or is only a few tens of feet thick in the Winkler anticline area. Here and in the area of the type section the next member is the only massive biohermal limestone reef of the formation. In both areas the reef limestone member is overlain by the thin-bedded suprareef limestone member containing the large foraminifer *Orbitolina.*

The measured thickness of the U-Bar Formation in the Winkler anticline area is about 1700 feet. This is thinner than in the Big Hatchet Mountains area where the formation is 3500 feet thick. Growth of the Winkler anticline during Cretaceous deposition accounts for the thinness of the U-Bar Formation.

The contact between the U-Bar Formation and the overlying Mojado Formation is conformable; limestone beds typical of U-Bar lithology are-interbedded with sandstone and shale beds of Mojado-type lithology through a transitional zone of about 30 feet. The contact is arbitrarily chosen at the base of the lowest sandstone bed, which is often green in this area.

Age and Correlation

The U-Bar Formation contains a large variety of fossils including the following: pelecypods such as oysters, pectens, and rudistids; gastropods, including one large specimen that is similar to the Trinity form *Lunatia? praegrandis;* colonial corals; echinoids; and foraminifers, including the large orbitolinas and the smaller miliolids. Fossil wood is present in some of the lower arenaceous beds. Faunas and floras from the U-Bar of this area have not been studied by specialists.

However, a gross fossil sequence that is very similar to the one in the type U-Bar Formation is present in the Walnut Wells quadrangle. The lowest beds of sandstone and shale contain lentils and strata of small silicified *Exogyra* that are diagnostic in the basal U-Bar beds of the type area. Higher beds, those which correspond to the oyster limestone member, contain small and large oysters, large pectens, and a variety of other pelecypods. Aptian ammonites are present in the oyster limestone member in the type area. The fauna of the reef limestone in each area includes corals and rudistids. Overlying thin beds of limestone in each area contain miliolids, orbitolinas, and rudistids. Near the top of the formation here, a fauna of small pelecypods and echinoids occurs that is similar to the pelecypod fauna dated as probable Fredericksburg age from near the top of the U-Bar Formation in the type area.

Though none of the mentioned forms are good index fossils, the similarity of the faunal sequence with that of the type U-Bar strongly suggests similarity of age. The distance between the U-Bar of the Winkler anticline and the type U-Bar is only 12 miles.

In the type area no index fossils are found in the lowest beds of the U-Bar Formation. The upper part of the oyster-bearing bioclastic limestone member is Aptian by European terminology and Trinity in terms of Gulf Coastal Plain terminology. The reef limestone and suprareef limestone members are of Albian age and of probable Fredericksburg age.

The U-Bar Formation cannot be correlated at present with formations in the nearby Little Hatchet Mountains. As presently understood (Lasky, 1947), several similar lithologic units occur at different levels in the Little Hatchet Mountains stratigraphic sequence. For instance, there are four massive reef limestone units assigned to three different limestone formations. At the present state of our knowledge, the U-Bar Formation could be equivalent to any one, several, or none of these formations. If correlation of the Cretaceous formations of the Walnut Wells quadrangle with those of the Little Hatchet Mountains only a few miles away is not possible, correlation of Walnut Wells formations with others at greater distances in the region cannot be made with confidence.

MOJADO FORMATION

The lower part of the Mojado Formation is exposed in an oval pattern surrounding the exposure of U-Bar Formation in the Winkler anticline. Scattered exposures are found from this area southward to near Cowboy Spring where the upper beds of the formation crop out. The lower and upper contacts are well exposed. Most of the middle of the formation is concealed by alluvium and Tertiary volcanic rocks; consequently, a complete stratigraphic section of the formation cannot be studied nor can the total thickness be determined. Alper measured the Bennett Creek stratigraphic section across the lower part of the formation.

An estimate of the maximum thickness of the formation may be made, assuming there are no structural complications in the concealed intervals, by plotting a cross section of the formation from base to top using the method described by Busk (1929, p. 19). This indicates a maximum thickness of 7800 feet. This figure is known to be excessive because of a large east-west fault, which is exposed only near the head of Bennett Creek; the fault undoubtedly projects beneath the young volcanics and alluvium where the thickness is computed, and it produces a duplication of Mojado beds and an apparent thickening (see geologic section AA', pl. 2). Other faults and minor folds may be present in the concealed interval.

Another way of estimating the thickness is to assume the Moj ado has the same thickness here as in the type area. There 4400 feet of beds lie between the base and the diagnostic faunal and floral zone present high in the formation in both areas. In the Walnut Wells area about 750 feet of beds lie between the faunal zone and the top of the formation. The total expected thickness of the Mojado in this area is therefore about 5150 feet (4400 plus 750). The actual thickness of the Mojado in this area is probably between 5150 feet and the maximum of 7800 feet, and it undoubtedly is much closer to the lower figure.

The Mojado Formation is predominantly sandstone with interbeds of shale. The basal contact with the U-Bar Formation is conformable and lies at the base of a 30-foot transitional zone of interbedded limestone, shale, and sandstone.

East of Cowboy Spring the formation is conformably overlain by the Cowboy Spring Formation, which consists mainly of limestone cobble conglomerate. Sandstone beds typical of Mojado lithology are interbedded with conglomerate beds characteristic of Cowboy Spring lithology through a transition zone several hundred feet thick, and the contact is chosen at the bed that divides the predominance of each lithology. The contact is well exposed only in a limited area; some quartz sandstone beds pass laterally into limestone conglomerate beds, the change being gradual due to variation in composition and size of the detritus.

Elsewhere, the Mojado is overlain with angular unconformity by Tertiary rocks. From the area of the Cowboy Spring Formation northward toward the axis of the Winkler anticline, the unconformity cuts progressively more deeply into the Cretaceous section. On the Winkler anticline the Cowboy Spring Formation and all but the lower few hundred feet of the Mojado Formation are gone.

In this quadrangle the Mojado Formation is composed chiefly of interbedded resistant sandstone, sandy shale, and white friable sandstone, and includes a few beds of impure limestone, limestone conglomerate, and sandstone conglomerate.

The resistant sandstone is mostly fine- and medium-grained but occasionally coarse-grained and consists of subangular to rounded quartz grains firmly cemented with calcite. The rock is cream, white, and orange on fresh fracture; it weathers orange, brown, and rarely black, and sometimes has banding; it is conspicuously cross laminated, has ripple marks, contains fossil wood, occurs in 4- to 20-foot beds, is resistant, and forms ledges.

The sandy shale contains fine- and medium-grained quartz, is brownish green on fresh fracture, weathers greenish brown, breaks into blocky fragments, is friable, contains fragmental plant fossils, has 2- to 4-inch laminae, is thin bedded, is nonresistant, and weathers as troughs between sandstone ledges.

The white friable sandstone consists of medium-grained quartz, is pure white when fresh, weathers cream, is usually cross laminated, contains fossil wood, is thick-bedded, is friable, and is nonresistant.

The impure limestone is somewhat argillaceous and arenaceous, has medium- to coarse-grained clastic texture, is gray, weathers brown, contains marine pelecypods and gastropods which weather bluish-gray, and occurs in lensing beds. These limestone beds are rare, and only one is noted in the measured section near its top. However, in the upper part of the formation about half a mile northeast of Cowboy Spring several richly fossiliferous impure marine limestones and associated terrestrial beds yield the only significant fauna and flora found in the formation—fossils that permit the formation to be correlated with the Mojado Formation of the Big Hatchet Mountains area.

The limestone conglomerate consists mostly of $1/_2$-inch pebbles of limestone, and it occurs in thin lenticular beds. The sandstone conglomerate consists of well-rounded 1-inch sandstone pebbles. A few beds of conglomerate composed of highly polished well-rounded chert pebbles occur in the upper 200 feet of the Mojado, and in the upper 100 feet lenses and beds of conglomerate composed of well-rounded limestone cobbles are common.

The formation is relatively uniform in lithology in that resistant sandstone beds alternate with nonresistant shale beds throughout. Beds are somewhat lenticular. White friable limestone increases in abundance upward. Conglomerate beds are not common except in the upper few hundred feet; several limestone conglomerate beds occur in the lower part and sandstone, limestone, and chert conglomerate beds occur in the upper part. Relative competence of interbedded shale and sandstone has produced boudinage structure in a few places.

The Bennett Creek stratigraphic section, measured in the lower part of the Mojado Formation, is given in the appendix.

Age and Correlation

A zone of marine limestone interbedded with terrestrial and marine sandstone and shale 4400 feet above the base of the Mojado Formation in the Big Hatchet Mountains area contains faunas and floras of late Washita age (Zeller, 1965). Among the important marine fossils are the ammonite *Engonoceras serpentinum* (Cragin) and the foraminifer *Haplostiche texana* (Conrad). In addition, the fern *Ternpskya minor* Read and Brown is found. This diagnostic zone is also present in the Mojado of the Sierra Rica.

In the Walnut Wells quadrangle the upper beds of the Mojado formation are exposed on the southern slope of the hill about half a mile northeast of Cowboy Spring near the center of sec. 13, T. 31 S., R. 18 W. Cropping out here is marine limestone interbedded with terrestrial sandstone and shale, a lithology which is similar to that of the Washita faunal and floral zone south of the Big Hatchet Mountains. In these beds Zeller recognized *Haplostiche texana, Engonoceras* sp., and *Tempskya* sp. He collected the funas and floras of these beds and, through the courtesy of Charles B. Read, the marine faunas were sent to W. A. Cobban, U.S. Geological Survey, for identification. Cobban's identifications of the fossils and his remarks are quoted below. The specimens are retained by the U.S. Geological Survey and were given the numbers shown. The forms that are also found in the Washita biotic zone of the Mojado Formation in the type section south of the Big Hatchet Mountains are indicated by an asterisk(•).

U.S.G.S. Mesozoic loc. D2096
  Foraminifer:
    **Haplostiche texana* (Conrad)
  Pelecypods:
    **Lopha* cf. *L. quadriplicata* (Shumard)
    Trigonia cf. *T. emoryi* Conrad
    **Protocardia texana* (Conrad)
    Corbula basiniformis Adkins
  Scaphopods:
    **Cadulus* sp.
    **Dentalium* sp.
  Gastropod:
    Drepanocheilus kiowana (Cragin)
  Cephalopod (ammonite):
    **Engonoceras serpentinum* (Cragin)

Remarks:

The pelecypods, gastropod, and ammonite suggest a late Comanche (Washita) age (late Albian).

U.S.G.S. Mesozoic loc. D2097 (same locality as D2096 but 23-31 feet higher in section).

Pelecypods:
- **Ostrea* sp.
- *Exogyra* sp.
- *Trigonia emoryi* Conrad
- **Protocardia texana* (Conrad)

Gastropods:
- *Turritella kansasensis* Meek
- **Actaeonella* sp.

Cephalopod:
- **Engonoceras serpentinum* (Cragin)

Remarks:

This fauna suggests a Washita age. In addition to the above fossils, a few fragments of a rudistid are present.

U.S.G.S. Mesozoic loc. D2098 (same locality as D2096 but 109-117 feet higher in section).

Foraminifer:
- **Haplostiche texana* (Conrad)

Pelecypod:
- **Protocardia texana* (Conrad)

Gastropod:
- *Drepanocheilus kiowana* (Cragin)

Remarks:

A Washita fauna.

Charles B. Read and Sidney R. Ash are studying the flora collected in the same locality. They have recognized a new species of *Ternpskya* which is related to *T. grandis* Read and Brown.

These fossils unquestionably establish the age of the beds as the same as the corresponding zone in the Big Hatchet Mountains area, which in terms of European stages is late Albian, and which in terms of the Gulf Coastal Plain sequence is late Washita. In the Walnut Wells quadrangle the formation lies conformably upon limestone of probable Trinity and Fredericksburg ages. Therefore the age of the formation here is regarded as ranging from Fredericksbug to late Washita. This formation is identified with confidence as the Mojado Formation of the Big Hatchet Peak quadrangle for the following reasons: Identical age of the fossil zones high in the formation in both areas, similar lithology and thickness, and position of the formation in each area above a limestone formation of probable Trinity and Fredericksburg age.

The Mojado Formation resembles the Corbett Sandstone of the nearby Little Hatchet Mountains in lithology and thickness, but as the

Corbett is currently regarded as of Trinity age (Lasky, 1947), correlation of the two formations cannot be made at present. Also, the Mojado resembles the Cintura Formation of southeastern Arizona and the Sarten Sandstone of Cooks Range, New Mexico. However, inasmuch as the Mojado cannot be correlated with a nearly identical formation in the Little Hatchet Mountains less than 20 miles away, it cannot be correlated with confidence with formations at greater distances.

COWBOY SPRING FORMATION

The Cowboy Spring Formation of Cretaceous age is here named for Cowboy Spring, southeast of which the formation has its only exposure in the quadrangle. This area is designated as the type locality; a type section was not measured. The formation consists chiefly of limestone cobble conglomerate.

Its base is conformable with the Mojado Formation. Sandstone and conglomerate beds typical of each formation are interbedded through a transitional zone several hundred feet thick. The two lithologies have an interfingering relationship and are completely gradational within the transition zone; beds of one lithology may be traced laterally into beds of the other.

The Cowboy Spring Formation consists of massive and resistant beds of limestone conglomerate separated by beds of sandstone, shale, claystone and tuff. Because of its greater abundance and resistance, the conglomerate is well exposed; the other rocks are present in erosional troughs between conglomerate beds and are mostly concealed.

The coarse detrital fraction of the conglomerate consists mainly of Cretaceous limestone in which *Orbitolina* and other common Cretaceous fossils are found. Some limestone fragments from Paleozoic formations are present. Sandstone detritus apparently derived from the Mojado Formation occurs throughout in small quantities and is predominant in some of the basal beds. No fragments of igneous rock were noted in the conglomerate. The coarse detritus ranges in size from granules to 5-foot boulders, but mainly consists of cobbles. Most are sub-rounded. The matrix is typically red calcareous and argillaceous arkose. The conglomerate is thick bedded and massive.

Interbedded sandstone is mostly red and arkosic, although a few beds are gray and green. Some sandstone is argillaceous, most is weakly cemented, and beds are thin. Grains are of fine and medium sand and are subangular. Most of the shale is bright red; some is gray and green. Shale occasionally passes laterally into sandy shale and shaly sandstone. The claystone is gray, unconsolidated, unstratified, and poorly exposed. A single 20-foot bed of latite porphyry tuff is exposed and may be traced for more than 2000 feet. The rock is red, purple, and white. Coarse crystals are of plagioclase, orthoclase, and black biotite; no quartz was noted. The groundmass is aphanitic.

In the limited area in which the Cowboy Spring Formation is exposed it is overlain by the basal limestone conglomerate and fanglomerate of the Tertiary System, a formation named Timberlake Fanglomerate in this report. Though the formation is a fanglomerate in most places, the beds that overlie the Cowboy Spring Formation consist of limestone cobble and boulder conglomerate. The contact is an angular unconformity. This Tertiary conglomerate and fanglomerate is composed of detritus derived from erosion of the Cowboy Spring Formation, and for this reason the lithologies of the two formations are similar. Where the Timberlake Fanglomerate rests upon the Mojado Formation, as on the hill at the center of section 13, T. 31 S., R. 18 W., the angular unconformity is clearly visible and the fanglomerate formation may be easily identified. However, to the south where limestone conglomerate of the Timberlake Fanglomerate rests upon limestone conglomerate of the Cowboy Spring Formation, separation is difficult because of the similar lithologies. Apparently the contact lies in the narrow valley along the northern boundary of section 24, T. 31 S., R. 18 W. Rocks exposed north of the valley are typical Cowboy Spring Formation. Resistant limestone conglomerate is interbedded with shale, sandstone, and other less resistant rocks. This interbedding produces a ribbed outcrop pattern; the beds dip about 35 degrees southward. South of the small valley limestone conglomerate is massive, has few nonresistant interbeds, and has a southern dip of only 9 degrees. Apparently this massive gently dipping limestone conglomerate is part of the Timberlake Fanglomerate, and the basal contact is concealed by alluvium in the small valley. Lithologically the rock of this massive conglomerate is the same as the conglomerate of the Cowboy Spring Formation.

Owing to the angular unconformity the original thickness of the formation is unknown. More than 1000 feet of the formation is exposed.

Age and Correlation

Because no fossils indigenous to the Cowboy Spring Formation were found, its age has not been determined from direct evidence. However, its age may be surmised from other evidence. The formation lies conformably upon the Mojado Formation of late Early Cretaceous age. Its coarse conglomeratic lithology suggests rapid deposition during a short time. Thus, its age may well correspond to that of the underlying rocks, Early Cretaceous. But, inasmuch as it lies above rocks that contain a late Early Cretaceous fauna, it could be of early Late Cretaceous age.

The possibility of the Cowboy Spring Formation being of Tertiary age is ruled out by two arguments. First, the base of the formation is interbedded with rocks that are characteristic of the lithology of the underlying Cretaceous formation, and its upper part is sharply truncated by an angular unconformity above which Tertiary rocks lie.

Therefore, it is genetically related to the underlying formation and not to the overlying one. Second, throughout southwestern New Mexico, Tertiary rocks are known to lie with angular unconformity upon pre-Tertiary rocks. Therefore, to conform with this regional obsevation, the fomation must be pre-Tertiary in age because it lies under the unconformity.

The constituents of this formation were undoubtedly derived locally, probably from early arching and erosion of the Winkler anticline or from a similar elevated structure now concealed under Tertiary volcanic rocks or alluvium; the formation probably is of local extent. Similar conditions elsewhere may have produced similar locally derived deposits also of limited extent. If this is the case, the formation was not continuous over the region and probably cannot be correlated lithologically with formations elsewhere, nor can it be correlated in age with others because its exact age is unknown.

Some observers have suggested that the formation be correlated with the Skunk Ranch Conglomerate of the Little Hatchet Mountains. Even though the lithologies of the two formations are similar, their ages may be quite different; the Skunk Ranch Conglomerate is considered by Lasky (1947, p. 26) to be of Trinity age, whereas the Cowboy Spring Formation lies upon Washita-age rocks and must be of Washita or later age. Unless additional study proves the Skunk Ranch Conglomerate to be of later age, the two formations cannot be correlated.

Tertiary Rocks

A thick sequence of weakly deformed predominantly volcanic rocks rests with angular unconformity upon strongly deformed Cretaceous and older rocks throughout the broad region in which this quadrangle lies. The volcanic sequence evidently blanketed the entire region, with the possible exception of local areas of active elevation. These rocks are known to be of Tertiary age in areas where fossils have been found. Because of the similarity of the rocks of this volcanic blanket throughout the region they are everywhere assigned to the Tertiary.

In the Walnut Wells quadrangle the entire sequence of volcanic rocks and associated sedimentary units, which are part of this regional blanket, is considered to be of Tertiary age. These rock units resemble others in the region which have been dated by plant fossils as Miocene and Pliocene (Callaghan, 1951; Kuellmer, 1954). Fossils from the Tertiary sequence of the Walnut Wells quadrangle were not collected or studied; hence, the age is not closely determined.

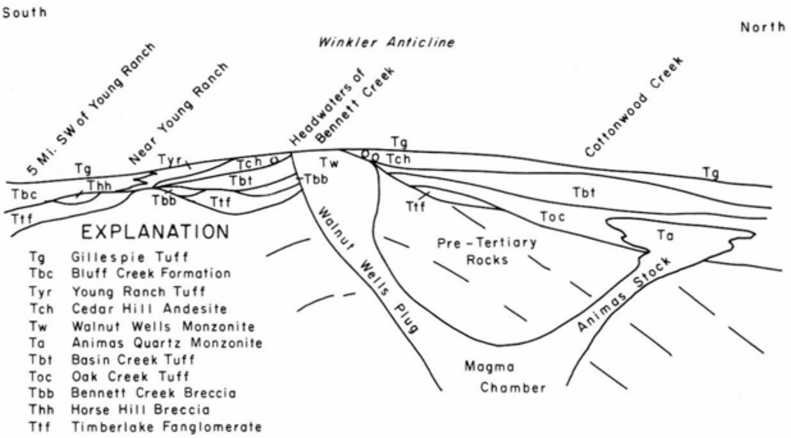
From base to top, Tertiary volcanic flows and sedimentary strata lie nearly parallel to one another with only minor breaks due to depositional and erosional events. These late rocks were deformed by gentle folds and high angle faults, but they were not subjected to the strong orogeny that deformed underlying rocks. Thus, the entire sequence differs greatly from underlying rocks in composition and in degree of structural deformation.

Prior to the initiation of the project on the Walnut Wells quadrangle, no detailed study of the Tertiary rocks had been made in the area; previous workers simply grouped these rocks together under such headings as "Tertiary volcanics." In this report these rocks are differentiated and described in some detail.

In the quadrangle about 90 percent of the exposed bedrock is Tertiary. As is typical in the region, extrusive rocks predominate. Several notable sedimentary formations are included in the section, and two intrusive masses are found. Each rock unit that is distinctive and crops out in an area large enough to be mapped separately is designated as a formation. Extrusive and sedimentary formations are lens-shaped in cross section due to the shape of the original deposit or to subsequent erosion; many do not extend beyond the borders of the quadrangle.

FIELD AND LABORATORY METHODS USED IN STUDY OF EXTRUSIVE ROCKS

Faulting, lensing, and facies changes make it difficult to determine the geologic relationships between the various extrusive rock units. Such relationships were determined by detailed study, especially of the field characteristics of the volcanic rocks. Figures 4 and 5 show diagrammati-



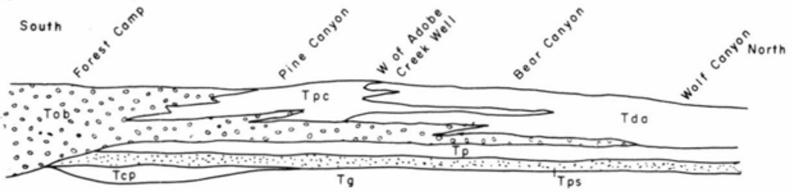
ORDER OF GEOLOGIC EVENTS

1. Erosion surface cut into pre-Tertiary rocks.
2. Deposition of Timberlake Fanglomerate followed by erosion.
3. Deposition of Bennett Creek Breccia. This formation appears to continue northward and to be equivalent to the lower breccia beds of the Oak Creek Tuff. Horse Hill Breccia may have been deposited simultaneously. Erosion then removed all but a remnant of the Horse Hill Breccia and part of the Bennett Creek Breccia.
4. Deposition of Oak Creek Tuff from a source in the Cottonwood Creek area.
5. Deposition of Basin Creek Tuff was probably next, though there is no direct evidence whether it was deposited before or after intrusion of the Animas Quartz Monzonite.
6. Intrusion of Animas Quartz Monzonite through the same vent that supplied the Oak Creek Tuff. At the same time or slightly later (after deposition of the Basin Creek Tuff), the Walnut Wells Monzonite was emplaced. Both intrusions apparently originated from the same magma chamber, which is shown hypothetically above. Erosion then exposed the Walnut Wells Monzonite.
7. Deposition of Cedar Hill Andesite. Boulders of the Walnut Wells Monzonite, indicated in the above sketch, were included in the basal andesite. Erosion cut into the Cedar Hill Andesite.
8. Deposition of Young Ranch Tuff upon Cedar Hill Andesite west of the Young Ranch. To the south the Bluff Creek Formation, which is equivalent to the Young Ranch Tuff, was deposited upon Timberlake Fanglomerate. Erosion occurred in the area of the Walnut Wells plug and probably in other local areas.
9. Deposition of Gillespie Tuff.

Figure 4

SCHEMATIC CROSS SECTION ILLUSTRATING ORIGINAL RELATIONSHIPS OF PRE-GILLESPIE TERTIARY FORMATIONS IN THE NORTHERN TWO-THIRDS OF THE WALNUT WELLS QUADRANGLE

Sketch is from north to south, does not follow a straight course, and is not to scale.



EXPLANATION

Tda	Double Adobe Latite
Tpc	Pine Canyon Formation
Tob	OK Bar Conglomerate
Tp	Park Tuff
Tps	Basal sandstone member of Park Tuff
Tcp	Center Peak Latite
Tg	Gillespie Tuff

ORDER OF GEOLOGIC EVENTS

1. Deposition of Gillespie Tuff.
2. Slight deformation and erosion.
3. Deposition of Center Peak Latite.
4. Slight deformation and erosion.
5. Deposition of basal sandstone member of Park Tuff.
6. Deposition of Park Tuff. Nondeposition or erosion of Park Tuff in southern part of area.
7. Beginning of OK Bar Conglomerate deposition.
8. Simultaneous deposition of Pine Canyon Formation and Double Adobe Latite. Volcanic flows of the two formations had different source areas, and they intertongued where they met. Deposition of the OK Bar Conglomerate continued to the south during extrusion of the flows.
9. Continued deposition of OK Bar Conglomerate to the south; most detritus derived from erosion of the Pine Canyon Formation.

Figure 5

SCHEMATIC CROSS SECTION ILLUSTRATING ORIGINAL RELATIONSHIPS OF POST-GILLESPIE TERTIARY FORMATIONS IN THE SOUTHWESTERN PART OF THE WALNUT WELLS QUADRANGLE

Indicated relationships occur west of Double Adobe Creek and Deer Creek. Sketch is from north to south, does not follow a straight course, and is not to scale.

cally the complex relationships of the formations and summarize the geologic events important to formation of the Tertiary rocks. The figures are distorted because of exaggeration of the vertical scale and because complex relationships are simplified and shown in only two dimensions.

The modified classification system of Cross, Iddings, Pirsson, and Washington (C.I.P.W. system; see Barth, 1931) based upon chemical composition was used to calculate standard mineral compositions or "norms" of the igneous rocks of the area. Each rock was classified on the basis of its norm and mode according to Wahlstrom (1947). Average compositions of plagioclase were determined by measuring extinction angles in combined albite-Carlsbad twins and albite twins in accordance with the Michel-Levy method and the F. E. Wright method. Textural terms for matrix are after Williams, Turner, and Gilbert (1954). Average amounts of phenocrysts in plutonic and flow rocks and coarse crystals in pyroclastic rocks were determined for many thin sections for each formation. Within some formations, there is variation in amounts, and sometimes in ratios, of phenocrysts or coarse crystals. Differentiation indices, explained by Thornton and Tuttle (1956), have been computed.

Most of the extrusive quartz latite formations in the area fall in chemical and mineral composition between quartz latite and rhyolite. These borderline rocks, with a silica percentage of approximately 66 percent, are lower in silica than Nockolds' (1954, p. 1012) average silica percentage for 22 rhyolites of approximately 74 percent; the quartz latites of the Animas Mountains also have 2 to 4.5 times more MgO than Nockolds' average rhyolite and usually twice the amount of Ca0 (table 1).

Chemical analyses of some of the igneous rocks of the Walnut Wells quadrangle are given in Table 1. Norms, mineral ratios, and differentiation indices of some of the igneous rocks of the quadrangle are given in Table 2.

TIMBERLAKE FANGLOMERATE

Exposures of the base of the Tertiary sequence, which rests with angular unconformity upon older rocks, are confined to the area extending from south of Gillespie Mountain to south of Cowboy Spring. Along part of the contact, volcanic rocks lie at the base, but in some places, especially in the vicinity of Cowboy Spring, the basal beds consist of limestone conglomerate and limestone-conglomerate fanglomerate. This formation is here named Timberlake Fanglomerate after Timberlake Ranch near where exposures of the formation are found. It is found in scattered exposures from near the mouth of Bennett Creek southward to the southern border of the quadrangle near the mouth of Walnut Creek.

The thickness of the Timberlake Fanglomerate varies from 0 to possibly 500 feet. Abrupt thickness changes occur which resulted, in part, from deposition of the fanglomerate in sharp erosional or fault depressions of local extent on the pre-Timberlake surface. Also, pre-volcanic erosion removed the top of the fanglomerate in some areas. It is overlain both disconformably and conformably by extrusive rocks.

The formation consists largely of limestone-cobble conglomerate, but east of Cowboy Spring it also contains masses of fanglomerate composed of boulders and blocks of limestone conglomerate up to 200 feet

TABLE 1. CHEMICAL ANALYSES OF SOME IGNEOUS ROCKS OF THE WALNUT WELLS QUADRANGLE

sample nos.*	10	9	5	B6	1	3	A6	707	14	Nockolds' (1954) average chemical composition of 22 rhyolites
SiO_2	65.90	77.16	67.04	58.96	57.47	61.15	66.08	63.47	64.73	74.2
TiO_2	0.85	0.27	0.50	0.74	0.90	0.77	0.59	0.69	0.60	0.2
Al_2O_3	16.46	11.47	16.59	16.69	17.95	18.19	12.23	16.95	17.40	13.6
Fe_2O_3	2.71	1.36	2.68	5.87	5.16	3.69	7.40	3.08	3.64	1.3
FeO	0.92	0.07	0.35	0.42	1.21	0.92	0.71	1.56	0.36	0.8
MnO	0.07	0.03	0.01	0.03	0.06	0.05	0.06	0.07	0.03	———
MgO	0.81	0.15	0.86	2.53	3.43	1.84	1.31	1.73	1.17	0.3
CaO	2.42	0.19	2.55	5.40	5.66	3.46	2.52	3.70	1.91	1.1
Na_2O	3.89	3.58	3.50	3.12	3.31	4.07	3.85	3.94	3.85	3.0
K_2O	5.07	4.74	4.02	2.62	2.73	3.45	3.95	3.65	4.14	5.4
P_2O_5	0.18	0.08	0.12	0.10	0.17	0.15	0.11	0.10	0.17	0.1
H_2O+	0.45	0.67	1.04	1.43	1.32	1.46	0.62	0.75	1.61	———
H_2O-	0.10	0.23	0.62	1.58	0.95	0.66	0.21	0.20	0.58	———
CO_2	0.19	0.00	0.00	0.00	0.00	0.00	0.34	0.16	0.00	———
	100.02	100.00	99.88	99.49	100.32	99.86	99.98	100.05	100.19	100.0

*sample numbers:

10	Double Adobe Latite
9	Park Tuff (rhyolite)
5	Gillespite Tuff (quartz latite)
B6	Cedar Hill Andesite
1	Cedar Hill Andesite
3	Walnut Wells Monzonite
A6	Animas Quartz Monzonite
707	Animas Quartz Monzonite
14	Oak Creek Tuff (quartz latite)

Analyst: H. B. Wiik, Helsinki, Finland.

TABLE 2. NORMS, MINERAL RATIOS, AND DIFFERENTIATION INDICES OF SOME IGNEOUS ROCKS OF THE WALNUT WELLS QUADRANGLE

Standard mineral norms (percent) and C.I.P.W. classifications sample numbers*	10	9	5	B6	1	3	A6	707	14
quartz	18.21	37.98	25.06	16.28	11.24	14.18	23.68	16.64	21.03
orthoclase	30.06	27.84	23.94	15.59	16.14	20.60	23.38	21.71	24.49
albite	33.04	30.42	29.37	26.22	27.80	34.62	32.52	33.57	32.52
anorthite	10.02		11.69	23.93	26.15	16.41	4.45	16.41	8.62
corundum	.82	.41	2.24			1.63		.41	3.47
wollastonite				.46	.46		2.09		
enstatite	2.01	.40	2.11	6.33	8.53	4.62	3.21	4.32	2.91
ferrosilite									
magnetite	.69				1.62	.93	.93	3.24	
ilmenite	1.67	.15	.76	.91	1.67	1.52	1.06	1.37	.76
apatite	.33	.33	.33	.33	.33	.33	.33	.33	.33
hematite	2.24	1.44	2.71	5.91	3.99	3.03	6.71	.80	3.67
rutile		.16	.08						.24
titanite				.59					
calcite	.40						.80	.40	
Totals	99.49	99.13	98.29	96.55	97.93	97.87	99.16	99.20	98.04
C.I.P.W. classifications	I 423	I 313	I 423	II 434	II 434	I 424	I 423	I 423	I 423
Mineral ratios									
salic/femic	12.55	38.97	15.41	5.64	4.90	8.38	7.34	8.48	11.39
quartz/feldspar	.25	.65	.39	.25	.16	.20	.39	.23	.32
alkali/lime	3.25	.0	2.36	.91	.87	1.75	6.5	1.75	3.42
K_2O/Na_2O	.86	.86	.77	.56	.55	.56	.68	.61	.71
Differentiation indices	81.31	96.24	78.37	58.09	55.18	69.40	79.58	71.92	78.04

*sample numbers:
10 Double Adobe Latite
9 Park Tuff (rhyolite)
5 Gillespie Tuff (quartz latite)
B6 Cedar Hill Andesite
1 Cedar Hill Andesite
3 Walnut Wells Monzonite
A6 Animas Quartz Monzonite
707 Animas Quartz Monzonite
14 Oak Creek Tuff (quartz latite)

in diameter. Some blocks are so large that the bedding within the blocks may be mistaken for the bedding of the Timberlake Fanglomerate. In this locality the detritus of the formation was derived from the Cowboy Spring Formation. Elsewhere the detritus seldom exceeds cobble size and is identical to the detritus of the Cowboy Spring Formation, but whether it was derived from the reworking of Cowboy Spring cobbles is not known. As in the Cowboy Spring Formation, the cobbles are subrounded and consist mostly of Cretaceous limestone with minor quantities of sandstone and Paleozoic limestone. The only volcanic rock noted is near the top of the formation on the south and southeast sides of Cedar Hill. The matrix of the formation varies from red argillaceous sandstone to limestone conglomerate of all grain sizes. Unlike the Cowboy Spring Formation, there is practically no sandstone, shale, or claystone interbedded with the conglomerate and fanglomerate.

In a deep arroyo northeast of Cowboy Spring where the contact between the Timberlake Fanglomerate and the overlying Basin Creek Tuff is exposed, the upper 20 to 50 feet of beds consists of boulders of limestone, limestone conglomerate, and volcanic tuff, and the uppermost few feet consists of volcanic-rock conglomerate with very few pieces of limestone. Basal beds of the overlying tuff contain scattered limestone boulders. Here the contact between the tuff and fanglomerate is gradational and therefore conformable.

As mentioned earlier, the Timberlake Fanglomerate is so similar to the Cowboy Spring Formation that their differentiation is difficult where the two formations are in contact. North of Cowboy Spring where the Cowboy Spring Formation is missing and the Timberlake Fanglomerate lies upon the sandstone of the Mojado Formation, the Timberlake is easily recognized. South of the known exposures of Cowboy Spring Formation, several outcrops of limestone-cobble conglomerate underlie extrusive rocks. The exposures are small and the conglomerate is too massive to reveal the dip. There is no indication whether or not these beds lie parallel to the overlying extrusive rocks. The conglomerate is identical to those of both the Cowboy Spring Formation and Timberlake Fanglomerate and is similar to a limestone conglomerate bed found in the Oak Creek Tuff north of Winkler Ranch. There is no direct way to tell to which of the formations this conglomerate belongs. Because the conglomerate exposures lie at the base of the Tertiary extrusive rocks it seems most likely that they are Tertiary in age and are therefore Timberlake Fanglomerate. They are mapped as such.

No fossils native to the Timberlake Fanglomerate were found, and so its age can be determined only from indirect evidence. The formation lies above a sharp angular unconformity, and it is overlain by gently dipping Tertiary extrusive rocks whose beds are parallel to those in the fanglomerate. Thus, the Timberlake Fanglomerate is more closely related to the overlying Tertiary extrusive rocks than to the underlying Cretaceous rocks; it is considered as Tertiary in age.

A similar Tertiary basal limestone fanglomerate is found in Mojado Pass south of the Big Hatchet Mountains (Zeller, 1965). However, it consists mainly of angular boulders of Paleozoic limestone derived from erosion of the ancestral Big Hatchet Mountains. Elsewhere in the region clastic beds are found at the base of the Tertiary section. In all places the detritus was locally derived and the deposits are probably of local extent. These clastic beds did not form a continuous blanket deposit throughout the region, and no fossils indigenous to the beds are known which would date them; therefore, precise correlation is impossible. Perhaps they may be roughly equivalent, however, because they all represent periods of conglomerate deposition that preceded Tertiary volcanism.

HORSE HILL BRECCIA

The only exposure of the Horse Hill Breccia is in an area south of Cowboy Creek and east of Horse Hill. It probably overlies the Timberlake Fanglomerate and is unconformably overlain by the Bluff Creek Formation and the Young Ranch Tuff. Its thickness varies from 0 to 150 feet.

The formation consists of heterogeneous rhyolitic pyroclastic rocks of tuff, agglomerate, and tuff breccia. The breccia is white to red with only minor amounts of broken quartz and feldspar crystals, and it contains many foreign, angular, 1/2- to 3/4-inch fragments. Microscopic examination shows that the bulk of the breccia contains less than 7 percent crystals of quartz and sanidine, and less than 1 1/2 percent of plagioclase (An 24). Crystals are less than 2 mm long, are fragmental, and are corroded. The matrix is cryptocrystalline.

This formation appears to be a thin remnant of early Tertiary volcanism. It probably was inclined gently to the south and was mostly eroded before the deposition of younger volcanic rocks.

BENNETT CREEK BRECCIA

This formation is named for exposures south of Bennett Creek. In places it lies with angular unconformity upon the Mojado Formation, and elsewhere it rests with erosional unconformity upon the Timberlake Fanglomerate. The Bennett Creek Breccia is overlain disconformably by the Basin Creek Tuff.

The Bennett Creek Breccia, which is of quartz latite composition, ranges in thickness from 0 to 100 feet. It consists mainly of white tuff but has many large angular and subangular foreign fragments of altered andesite, rhyolite breccia, sandstone, conglomerate, and fanglomerate (fig. 6); the fragments range in length up to 12 feet. Some of the foreign material may have been washed into the formation from hills of older rocks exposed during deposition.

The tuffaceous matrix is soft, white, and almost entirely devoid of crystals. Microscopic examination shows that some specimens have 5 percent sanidine crystals up to 2 mm long, 3 percent quartz crystals up to 1/2 mm across, and less than V2 percent of reddish brown biotite and magnetite. The crystals are fragmental, fractured, and corroded. Feldspars and matrix have been altered to calcite and clay minerals. Thin section analyses show that foreign fragments are common.

At one place near the head of Bennett Creek, the formation rests upon the uppermost limestone of the U-Bar Formation, but basal beds of the breccia formation contain no limestone detritus. A few hundred feet to the south a thick prominent exposure of limestone fanglomerate seems, at first glance, to be a bed within the Bennett Creek Breccia. However, details of the occurrence indicate that the thickest and most massive fanglomerate, which is free of volcanic detritus, represents a remnant ridge of Timberlake Fanglomerate on the pre-Bennett Creek Breccia erosion surface. Timberlake Fanglomerate may be seen resting directly upon Mojado Formation in a small exposure in Bennett Creek

Figure 6

FOREIGN FRAGMENT IN THE BENNETT CREEK BRECCIA

Pick lies within area of 10 foot diameter fragment which is darker than enclosing rock. Location NE¼ sec. 11, T. 31 S., R. 18 W.

canyon. Evidently Bennett Creek deposition started with a fall of volcanic ash during which there was no chance for rocks from earlier formations to become enclosed. Then a pause in deposition of ash allowed erosion to denude and cut the Timberlake Fanglomerate ridge and to form flanking deposits of limestone fanglomerate with a matrix of tuff.

OAK CREEK TUFF

The Oak Creek Tuff is named for its exposures near Oak Creek. This tuff, which is of quartz latite composition, is the most prominent and oldest exposed formation north of Gillespie Mountain and extends beyond the northern boundary of the Walnut Wells quadrangle. The Oak Creek Tuff rests with angular unconformity upon Cretaceous rocks and Timberlake Fanglomerate on the northeastern nose of the Winkler anticline. It is overlain with apparent conformity by the Basin Creek Tuff. The Oak Creek Tuff is missing on the northwestern flank of the Winkler anticline where the Basin Creek Tuff rests upon Cretaceous rocks.

The Oak Creek Tuff, which is over 1500 feet thick near Valentine Creek, thins southward and pinches out south of Gillespie Mountain. The basal part of the formation, consisting of tuffaceous agglomerate and breccia, in most places is thicker than 125 feet. These lower heterogeneous pyroclastic beds, which are white, yellow, or light pink, are usually soft and lack banding. Small (1-2 mm) angular clear quartz crystals, lathlike feldspar crystals up to 3 mm long, and euhedral biotite crystals up to 2 mm long are present; locally crystals are absent. Parts of the basal zone, especially near the Combined Minerals Corporation manganese mine, contain spherules up to 2 inches in diameter.

Lapilli and some bombs are scattered throughout the basal tuffaceous agglomerate and breccia zone. Outcrops of these lower beds are scattered; usually exposures are at the bottoms of stream channels. Hence it is almost impossible to know if there is a systematic change in color, crystals, induration, or fragments laterally or vertically within the basal zone. Apparently, the lower part has fewer and smaller crystals than the upper part. The zone resembles the Bennett Creek Breccia to which it might be in part equivalent.

Between Millsite and Ash Creeks, east of the main mountain mass, a group of low hills (principally in sec. 24, T. 30 S., R. 18 W.) composed of the basal part of the Oak Creek Tuff extends into the valley. Here a thin bed of limestone cobble and boulder conglomerate is interbedded with the volcanic rocks. In some places the bed of conglomerate consists of volcanic detritus with only scattered limestone boulders. Some of the boulders are extremely large and have diameters up to 20 feet. One boulder measures about 100 feet by 50 feet. Fossils and lithology indicate that most of the limestone detritus was probably derived from the Epitaph Dolomite and the Concha Limestone, formations which must have been exposed nearby during early Oak Creek time.

The main mass of Oak Creek Tuff, which rests upon the basal tuffaceous agglomerate and breccia beds, is usually green or dark purple and is well indurated. Megascopic field observations indicate that the most common crystals are subhedral pink feldspar up to 6 mm long, euhedral and subhedral grayish quartz up to 5 mm in diameter, and pseudo-hexagonal black biotite up to 4 mm across. The rock contains numerous 1/2- to 11/2-inch green and red foreign fragments.

Streaks and lenses of the same composition as the rest of the rock are conspicuous; they are green and purple but are either slightly lighter or darker than adjacent rock. The streaks are probably due to flowage; they vary in size from less than 2.5 cm long, 1 cm wide, and 1/2 cm thick, to about 1 m long, 5 cm wide, and 1 cm thick. The lenses were probably formed by compaction of loose tuffaceous material by the weight of the formation; they generally are only about 15 mm long, 8 mm wide, and 4 mm thick. No cavities are present now, but they may have been present and later flattened. The streaks and lenses are planar structures; their attitudes are shown on the geologic map (pl. 1). The rock weathers to a rusty color, with many holes where fragments have weathered out.

The Oak Creek Tuff generally forms hills with fairly steep slopes covered with platy blocks. The rock has vertical joints, though the joints are not as well developed as the columnar joints typical of welded tuffs. The rock has been brecciated along normal faults, and manganese mineralization occurs in fault zones in the formation along the western flank of the Animas Mountains. Except for the basal part, this formation is devoid of marker horizons and is massive and uniform throughout its vertical and lateral extent.

Petrographic description of the Oak Creek Tuff is given in Table 3. Chemical compositions and norms are listed in Tables 1 and 2.

Field and laboratory studies indicate that the Oak Creek Tuff and the Animas Quartz Monzonite were derived from the same magma that ascended through the channel occupied by the Animas stock; extrusion of the tuff was slightly earlier than emplacement of the quartz monzonite of the stock. The following evidence supports this hypothesis: (1) The tuff thins when traced away from the stock, having a thickness of more than 1500 feet near the stock and pinching out 6 miles to the south. (2) Planar structures in the tuff dip away from the stock and in places are parallel to the contact between the tuff and the intrusive. (3) Linear flow streaks trend transversely to the stock and plunge away from it. (4) Megascopic crystals in the tuff decrease in size away from the stock. (5) Chemical compositions of intrusive and extrusive are similar (table 1). (6) Mineral compositions of crystals in the tuff and quartz monzonite are similar. (7) The fine-grained facies of the intrusive rock is strikingly similar to the extrusive rock in texture, grain-size, and mineral

TABLE 3. PETROGRAPHIC DESCRIPTION OF THE OAK CREEK TUFF OF QUARTZ LATITE COMPOSITION

Percent coarse crystals: 35% average; 25-50% range

	Volume percentage	Average size (mm)	Shape	Color	Character
Coarse crystals					
quartz	8	.80	subhedral to anhedral	colorless	rounded, broken and fractured, some partially twinned
plagioclase (An 30)	16*	.60	subhedral to euhedral	colorless	corroded, broken crystals, clay alteration, albite and Carlsbad twinning
sanidine	10*	.60	subhedral to euhedral	colorless	corroded, broken crystals, some clay alteration, some crystals are zoned
biotite	~1 to 2	.40	subhedral to euhedral	brown	includes magnetite, zircon; curved plates, corroded; magnetite rims
hornblende	1	1.05	subhedral to euhedral	green	pleochroic, corroded, altered; magnetite rims; twinning; in some sections hornblende is almost gone
magnetite	~1	.35	subhedral to anhedral	black	surrounds biotite; in biotite mainly in groundmass
Accessory minerals					
zircon, apatite			subhedral to euhedral		in megascopic crystals and in matrix
Alteration minerals					
clay and sericite—trace					alteration of feldspars

Matrix

glassy-cryptocrystalline—(some thin sections devitrified—fine grained)
some sections show compaction or flow features
stained by limonite
commonly includes zenolithic fragments

Note: In some thin sections ratio of plagioclase crystals to sanidine crystals is approximately equal to or less than 1.

Pyroxene is indicated by remnant euhedral outlines in some sections, though it is completely altered to iron minerals.

composition of crystals. Statistical analysis of the shapes of zircon crystals in the various extrusive and intrusive rock units of the area indicate that the Animas Quartz Monzonite, the Walnut Wells Monzonite, and the Oak Creek Tuff all originated from the same magma.

As mentioned, the size of crystals in the tuff decreases away from the stock; this fact was confirmed by a few measurements, but a systematic statistical study of crystal size was not carried out. At Valentine Creek, adjacent to the stock, the tuff has feldspar crystals up to 6 mm long, quartz crystals up to 5 mm in diameter, and biotite crystals up to 4 mm across. About 1 mile from the contact with the quartz monzonite (NE corner of sec. 33, T. 29 S., R. 18 W.), crystals in the tuff are smaller; feldspar ranges up to 3 mm long, quartz ranges up to 2.5 mm in diameter, and biotite ranges up to 2 mm across. The crystals measured were from about the same horizon of the tuff, that horizon being the base of the massive purple and green tuff that forms the bulk of the formation.

The Oak Creek Tuff is a fragmental pyroclastic rock. During the first stage of deposition, more than 125 feet of agglomerate and breccia was laid down. This was followed by deposition of more than 1500 feet of fragmental tuff. The tuff was deposited as a viscous mixture of fragmental solids and crystals. Upon cooling, vertical jointing developed.

BASIN CREEK TUFF

The Basin Creek Tuff, named for exposures at the headwaters of Basin Creek, is also exposed in two other areas: on the northern part of Gillespie Mountain, and south of Bennett Creek. The Basin Creek Tuff rests with apparent conformity upon the Oak Creek Tuff north of Gillespie Mountain, unconformably upon Cretaceous rocks on the northwestern flank of Winkler anticline, disconformably upon the Bennett Creek Breccia south of Bennett Creek, and conformably upon the Timberlake Fanglomerate on the south side of Cedar Hill. The Cedar Hill Andesite rests with apparent conformity and disconformably on the Basin Creek Tuff. The tuff ranges in thickness from 700 feet, north of Gillespie Mountain, to 150 feet, south of Bennett Creek, and it pinches out south of Cedar Hill.

The source zone is located at the headwaters of Basin Creek, mostly in the S1/2 sec. 9 and the N1/2 sec. 16, T. 30 S., R. 18 W. In this vent zone the Basin Creek Tuff is an irregular, elongated, funnel-shaped mass which in part intrudes and in part overlies the Oak Creek Tuff. The Basin Creek Tuff consists of tuff, tuff breccia, and tuff agglomerate of quartz latite composition. Most flow lines are vertical, and biotite flakes are parallel to the flow lines; in places flow planes dip erratically. Fresh tuff is light purple to pink, and the weathered color of the formation is pink. According to megascopic field observation, the tuff contains numerous euhedral and subhedral clear quartz crystals up to about 4 mm in diameter, subhedral lath-shaped white feldspar crystals up to about 6.5 mm long, and euhedral bronze biotite crystals up to about 1.5 mm across. The rock is soft and breaks easily. Reddish brown lapilli and angular 1/2- to 11/2-inch fragments are common; many weather out leaving small holes from half an inch to an inch in diameter. Fragmental bombs are rare. Weathering of the formation produces cliffs, many large slender pedestals, and long rounded columns. Huge angular boulders of tuff form talus debris at the base of the cliffs. Weathering produces exfoliation sheets which dislodge from the rock. North of Gillespie Mountain the Basin Creek Tuff lacks well-developed columnar jointing or noticeable bedding and is very massive. The basal part of the formation which rests upon the Oak Creek Tuff is the same as the rock of the source zone, except that the basal part lacks flow bands.

In the area south of Bennett Creek, the Basin Creek Tuff is similar to the formation in its source area. The tuff is light purple to pink, and megascopic crystals are of clear quartz, white feldspar laths, and bronze biotite. The aphanitic matrix is soft and is more friable than the matrix in the source area. The tuff is not vesicular and lacks banding. The formation weathers pink and forms pedestals, columns, and cliffs; it is generally less resistant to erosion. Indigenous lapilli are the predominant fragments; they weather out to form small holes less than an inch across. Columnar jointing is absent. The formation is notably thick-bedded (3 to 20-foot beds) in contrast to the massive, non-bedded nature of the tuff north of Gillespie Mountain. In addition to the predominant brownish red and green lapilli characteristic of the formation in the north, the tuff in the south has many bomb-sized fragments (fig. 7). Also present are some extraneous fragments of andesite, limestone, red sandstone, brown sandstone, fossiliferous limestone, fusulinid-rich limestone, and quartz latite. The fragments vary in size from less than 1 inch to 5 feet in diameter. Some of the limestone fragments are only a quarter of an inch in diameter, are completely unaltered, and have not been recrystallized. Most of the native lapilli and bombs are rounded; some are subangular and angular. Most of the extraneous material is subangular and completely unsorted. No systematic distribution of quantity or size of fragments within the formation was noted. On the south side of Cedar Hill the basal beds contain numerous limestone boulders and grade downward into the limestone conglomerate of the Timberlake Fanglomera te.

In the source zone the Basin Creek Tuff intrudes and overlaps the Oak Creek Tuff as a mushroom-shaped body about 700 feet thick. It thins southward to about 150 feet at Bennett Creek and pinches out south of Cedar Hill. The tuff changes laterally from a uniform, massive, soft, pinkish tuff with lapilli and some bombs in the source zone to a heterogeneous, bedded, soft to friable, pinkish tuffaceous agglomerate and breccia with lapilli, bombs, and unsorted foreign fragments

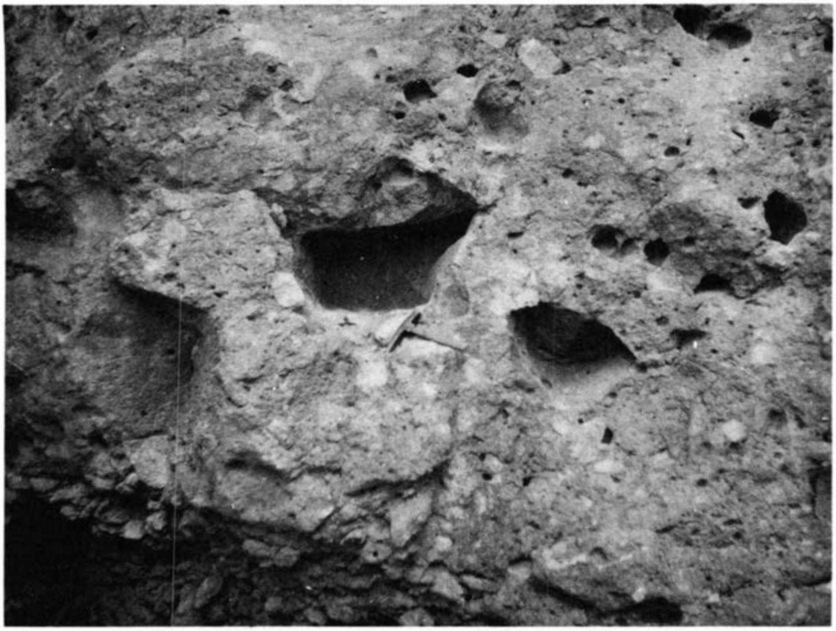


Figure 7

FRAGMENTS IN THE BASIN CREEK TUFF

Location SE¼ sec. 11, T. 31 S., R. 18 W.

toward the south. The tuffaceous agglomerate and breccia of the southern area probably were waterlain in part, as indicated by the bedding of the tuff and the lack of alteration, assimilation, formation of reaction rims, or recrystallization of 1/4-inch limestone fragments embedded in the tuff. The underlying Oak Creek Tuff pinches out south of Gillespie Mountain. In the area immediately south of Bennett Creek, the only volcanic formation older than the Basin Creek Tuff is the Bennett Creek Breccia, which occurs in thin, lenticular, scattered deposits.

The Bennett Creek Breccia probably did not completely cover the irregular hills of pre-Tertiary sedimentary rock exposed during Bennett Creek deposition. Some of these hills probably existed also when the Basin Creek Tuff was being deposited, and sedimentary fragments washed from such hills became embedded in the formation.

Petrographic description of the Basin Creek Tuff is shown in Table 4.

THE ANIMAS QUARTZ MONZONITE PORPHYRY STOCK

An intrusive stock of quartz monzonite porphyry exposed in the north-central part of the Walnut Wells quadrangle is called Animas stock from its location in the Animas Mountains, and the rock unit is called Animas Quartz Monzonite. The stock is almost four miles long and varies from less than a quarter of a mile to over 21/2 miles wide. The elevation of the exposed rock varies from 4800 to 6300 feet. The stock is an irregularly funnel-shaped intrusion in which part of the roof of overlying rocks has been faulted. Oak Creek Tuff lies on the sides and top of the stock. The outer borders are sharp and dip toward the center of the mass.

TABLE 4. PETROGRAPHIC DESCRIPTION OF THE BASIN CREEK TUFF OF QUARTZ LATITE COMPOSITION

Percent coarse crystals: 30% average; 20-45% range

	Volume percentage	Size (mm)	Shape	Color	Character
Coarse crystals					
sanidine	15	<.20 to 6.5 1.2 average	euhedral to subhedral	colorless	commonly zoned and twinned; fragmental; sometimes badly altered to clay
quartz	8	<.20 to 3.65 .80 average	subhedral to anhedral	colorless	corroded; fractured; generally clear; fractures filled by matrix
plagioclase (An 26)*	5	<.20 to 3.35 1.00 average	euhedral to subhedral	colorless	corroded; altered to sericite; includes apatite, magnetite, and biotite; some crystal fragments; some grouping of phenocrysts; albite and Carlsbad twinning
magnetite	2	<.20 to .80 .25 average	euhedral to subhedral	black	in plagioclase, biotite and matrix; commonly forms rims around biotite; rarely rimmed by biotite
biotite	1	<.20 to 1.20 .40 average	euhedral to subhedral	brown	corroded; frayed edges
Accessory minerals					
zircon, apatite			in matrix and in megascopic crystals		
Alteration minerals					
limonite stain					
sericite and clay			alteration of feldspars and matrix		
Matrix					
	glassy to cryptocrystalline; some partially devitrified; contains foreign rock fragments				

*some plagioclase crystals up to An 29 are present

Megascopically, the intrusive rock is pinkish gray and porphyritic with pink phenocrysts of potash feldspar up to 11/2 cm long, greenish-gray plagioclase phenocrysts up to 1 cm long, and gray quartz phenocrysts up to 8 mm in diameter. Black to green biotite phenocrysts up to 7 mm across are the most abundant femic phenocrysts. The crystal size of the matrix varies from less than 1 mm to 2 mm. The relative abundance of phenocrysts to groundmass varies from more than 70 percent phenocrysts to more than 80 percent groundmass. The rock is flow banded in many parts of the exposed area, especially near border zones. The bands are all of the same composition and consist of alternating layers in which fine-grained matrix and coarse-grained phenocrysts have been concentrated and aligned. The banding reflects alternating concentrations of liquid and crystals as the magma crystallized. The bands are from less than an inch to several feet wide, and they are from a few feet to tens of feet long. Generally the coarser-grained layers are the thicker. Most zones of banded rock are less than 20 feet wide, but some are nearly 50 feet wide. The bands are commonly contorted by primary folding (fig. 8). The dip of the bands is toward the core zone of the stock and away from the borders.

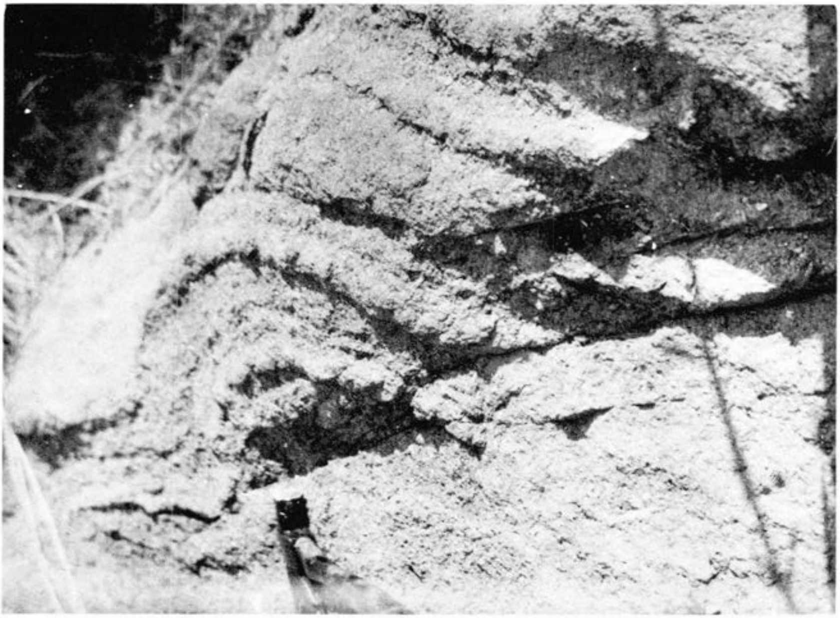


Figure 8

TEXTURAL BANDS IN THE QUARTZ MONZONITE PORPHYRY OF THE ANIMAS STOCK

Location NW¼ sec. 2, T. 30 S., R. 18 W.

The intrusive rock lacks gas cavities and is not streaked. Phenocrysts are not noticeably oriented in the main mass. Joints occur in the border zones and are usually approximately perpendicular to the contact. The stock is not brecciated, except along the fault zones. Along the northern fault between the intrusive and extrusive rocks, slickensides and gouge are present in both the coarse grained and fine grained bands.

Xenoliths are generally scarce, but when present they include the following rock types: quartz latite, schist, granite, sandstone, andesite, and skarn. The inclusions vary in size from less than an inch to 25 feet in diameter. Contacts between xenoliths and quartz monzonite are almost always sharp. The highest concentration of xenoliths is in the eastern part of the intrusion.

The quartz monzonite weathers into spheroidal, buff-colored boulders and rounded slopes in marked contrast to the resistant angular-weathered Oak Creek Tuff. The phenocrysts, when freed from the friable matrix by weathering, form an arkosic residual deposit; the feldspars break down to clay minerals.

Petrographic description of the Animas Quartz Monzonite is shown in Table 5.

Chemical composition and concentrations of heavy minerals indicate that slight differentiation took place in this funnel-shaped intrusion. Table 1 shows that specimen 707 (400 feet lower in elevation than specimen A6) has less $Si0_2$ and K_20, and more CaO, MgO, and Na_2O than sample A6. The total heavy residue in the main stock per equal weight of rock increases from .016 gm to .258 gm for a 900-foot difference in elevation.

Field, chemical, and petrographic data previously listed (p. 34) and also zircon data (p. 65) indicate that the Oak Creek Tuff and the quartz monzonite ascended by the same channel and were derived from the same magma. The early gas-rich fragmental Oak Creek extrusive stage was followed by a shallow intrusive crystal-mush stage in which the magma spread out and intruded the extrusive cover. This intrusion gave rise to quartz latite xenoliths and roof pendants in the stock and quartz monzonite apophyses in the extrusive facies. Phenocrysts in the extrusive and intrusive rocks are essentially the same, with the exception that those in the intrusive rock are larger. The groundmass of the stock is generally coarser grained than that of the extrusive rock. The apophyses, the outer borders of the stock, and some of the bands have an aphanitic groundmass, and in these rocks the phenocrysts are also smaller than average for the main body. With the exception of being nonfragmental, the fine-grained phases of the intrusives are almost indistinguishable from the extrusive. Tables 1 and 2 demonstrate that the extrusive sample lies between the range of the two intrusive samples with regard to chemical composition, differentiation index, alkali/lime

TABLE 5. PETROGRAPHIC DESCRIPTION OF THE ANIMAS QUARTZ MONZONITE

Percent phenocrysts: 50% average; 15-85% range

	Volume percentage	Average size (mm)	Shape	Color	Character
Phenocrysts					
plagioclase (An 30)	29*	2.5	subhedral	colorless	Carlsbad, albite, and pericline twinning; corroded
orthoclase	13*	1.4	subhedral	colorless	Carlsbad twinning; corroded
quartz	5	.80	subhedral to anhedral	colorless	includes plagioclase, corroded
clinopyroxene	0 to 2	.45	subhedral	light green	non-pleochroic, corroded; rarely rims of chlorite and rims of Fe
magnetite, hematite	2	.25	subhedral to anhedral	black	occasional sphene rims
biotite	1 to 2	.55	subhedral to anhedral	red-brown	resorbed; includes magnetite, apatite and zircons
hornblende	trace[1]	.50	subhedral	brownish green	pleochroic; resorbed
Accessory minerals					
zircon, apatite, rutile, sphene	trace				
Alteration minerals					
calcite	trace				alteration of feldspar and groundmass
chlorite	trace				alteration of feldspar, femics, and groundmass
sericite	trace				alteration of feldspar
Matrix		~.18			aphanitic to fine-grained phaneritic, granular; quartz 20%; orthoclase 20%; biotite 1%; magnetite 1%; plagioclase <1-3%

* In some thin sections the ratio plagioclase phenocrysts/orthoclase phenocrysts=25/18

[1] One thin section in sixteen had hornblende.

ratio, and quartz/feldspar ratio. The extrusive sample is slightly more salic and more potassic than the intrusive specimens. The C.I.P.W. classification of extrusive and intrusive samples is identical.

THE WALNUT WELLS MONZONITE PORPHYRY PLUG

The Walnut Wells plug, named for the Walnut Wells quadrangle, is exposed in secs. 8, 9, 17, and 18, T. 31 S., R. 18 W., in the west central part of the quadrangle. The plug intrudes the Bennett Creek Breccia and is disconformably overlain by the Gillespie Tuff. On its western side it is bordered by the Cedar Hill Andesite and on its eastern side by Basin Creek Tuff. The body is almost 2 miles in diameter and is exposed over a 1000-foot vertical range. The eastern contact of the plug is along minor faults, some that are vertical and some that dip 70° toward the core.

The rock, a monzonite porphyry which is called Walnut Wells Monzonite, is light grayish green with red color bands; at a distance the outcrop looks red. It has about 20 to 45 percent phenocrysts embedded in an aphanitic matrix. The most common phenocrysts noted in the field are gray subhedral plagioclase up to 6 mm long. Black subhedral biotite phenocrysts up to 5 mm across are also common. Gray subhedral phenocrysts of potash feldspar and minor amounts of gray subhedral quartz phenocrysts are also present. Almost all the minerals in the red bands are themselves red. These bands occur throughout the body of the plug and have sharp contacts with the green parts of the rock.

The rock lacks gas cavities, streaks, and oriented phenocrysts. Jointing is not well developed. Along parts of the eastern side of the plug, the rock is brecciated and shows slickensides along minor faults. These faults are less than 30 feet in length and were formed during and after emplacement.

About 50 unoriented xenoliths of granite and aplite were observed. They have angular margins and range in size from less than 6 inches to 13 feet in diameter. The xenoliths are situated along the northeast border of the plug. They have no reaction rims and have sharp contacts with the surrounding rocks. A few xenoliths intruded by latite stringers weather out easily from the surrounding rock. Fewer than 10 quartz latite xenoliths, from 4 to 35 feet long, were found in the southeastern part of the plug. They also have sharp contacts with the intrusive rock and show no alteration effects.

The monzonite is fairly resistant to erosion and the plug has greater relief than most of the surrounding rocks. Upon weathering, the rock breaks down to tabular blocks which form talus deposits on the moderate slopes.

The following evidence suggests that this monzonitic body was emplaced at shallow depth: (1) aphanitic matrix and porphyritic texture; (2) lack of contact effects on xenoliths; (3) observed contacts with surrounding rocks are sharp; (4) corrosion and absorption effects in phenocrysts; and (5) position in geologic column.

The magma was probably partly (approximately 30 percent) crystallized when emplaced; this is indicated by the presence of phenocrysts in matrix along chilled margins. The contact between the Walnut Wells Monzonite and the Bennett Creek Breccia is definitely intrusive. Though the contacts of the monzonite with the Basin Creek Tuff are obscured by talus deposits, the map pattern indicates that the contacts are intrusive. No apophyses are found in the quartz latite of the surrounding Bennett Creek Tuff and Basin Creek Tuff, and there are very few quartz latite xenoliths in the monzonite; for these reasons, it seems likely that the magma filled an open vent blown out of the quartz latite extrusives.

The contacts between the plug and the Cedar Hill Andesite are also obscured by talus slides. No andesite zenoliths were found in the monzonite of the plug, nor were apophyses of the Walnut Wells Monzonite seen in the Cedar Hill Andesite. Fragments of the distinctive plug rock were observed in the basal breccia of the Cedar Hill Andesite which indicates that the Walnut Wells Monzonite was emplaced before the deposition of the Cedar Hill Andesite. The rock of the plug apparently formed a resistant hill from which detritus was eroded during the early stage of deposition of the Cedar Hill Andesite.

The mineral composition of the monzonite resembles that of the Animas stock more than that of the Cedar Hill Andesite or the Basin Creek Tuff (tables 4, 5, 6, and 7). The chemical composition of the monzonite of the plug (table 1) is intermediate between that of the Animas Quartz Monzonite and that of the Cedar Hill Andesite. These data plus the zircon data (Alper and Poldervaart, 1957) indicate that rocks from the Animas stock and the Walnut Wells plug probably were derived from the same parent magma. These two igneous bodies probably were emplaced simultaneously, or at least within a short period of geologic time.

Field relationships, though not conclusive, are not in conflict with the theory that the Animas stock and the Walnut Wells plug originated from the same parent magma at about the same time. Emplacement of the Walnut Wells Monzonite occurred after deposition of the Bennett Creek Breccia, which is probably equivalent to the basal beds of the Oak Creek Tuff. Emplacement of the monzonite was probably after deposition of the Basin Creek Tuff and was before deposition of the Cedar Hill Andesite. The Animas stock was emplaced after the deposition of the Oak Creek Tuff. However, because the Animas stock is not in contact with the Basin Creek or Cedar Hill formations, it is not known whether these extrusives were deposited before or after intrusion of the stock (fig. 4).

TABLE 6. PETROGRAPHIC DESCRIPTION OF THE WALNUT WELLS MONZONITE

Percent phenocrysts: 30% average; 20-45% range

	Volume percentage	Average size (mm)	Shape	Color	Character
Phenocrysts					
plagioclase (An 33)	16	.80	subhedral	colorless	glomeroporphyritic; corroded; zoned, (An 26) rims; includes magnetite, apatite and zircon; Carlsbad, pericline, albite twinning
orthoclase	10	.90	subhedral	colorless	fresh; zoned; slightly corroded; high 2V
clinopyroxene	2	.60	subhedral	colorless or light green	non-pleochroic; corroded; magnetite rims
biotite	2	.65	subhedral to euhedral	light brown to dark brown	corroded; rims of plagioclase and magnetite
Accessory minerals					
zircon, apatite	trace				mainly in phenocrysts
Matrix					
plagioclase	—19		subhedral	colorless	albite twinning; partly altered to sericite and clay
quartz	—18		anhedral	colorless	interstitial, clear and fresh
orthoclase	—30	<.02 to .09	anhedral to subhedral	colorless	altered in part to sericite
magnetite	2		anhedral	black	masses; altered to limonite
Alteration minerals					
hematite, limonite	<1 to 4		anhedral	red	few small crystals; mainly in cracks of rock; forms red bands in rock of same mineral composition
clay and sericite					alteration of plagioclase, orthoclase, and pyroxene

CEDAR HILL ANDESITE

The Cedar Hill Andesite is named for Cedar Hill where it is well exposed. It crops out from Cedar Hill westward along Cowboy Rim to the head of Gillespie Creek and along the western part of the Animas Mountains near the mouths of Thigpen and Cottonwood Creeks. The andesite is also exposed around the base of Gillespie Mountain and on small isolated hills north and northwest of the Young Ranch.

The Cedar Hill Andesite usually rests with apparent conformity on the Basin Creek Tuff, but in some localities the contact is disconformable. Locally near Gillespie Mountain a 10-foot sandstone unit lies between the andesite and the underlying tuff. The Gillespie Tuff appears to lie conformably on this andesite in most places. The Young Ranch Tuff rests disconformably upon the Cedar Hill Andesite.

The andesite sequence thins northeastward from a thickness of more than 300 feet in the vicinity of Henry's Cabin to 200 feet thick on the west flank of Gillespie Mountain, and to about 100 feet thick north of Gillespie Mountain (northern part of sec. 27, T. 30 S., R. 18 W.). This sequence of essentially horizontal strata also thins southeastward from Henry's Cabin along Cowboy Rim where it pinches out.

A zone of andesite tuff breccia about 20 feet thick generally lies at the base of the formation. At Cedar Hill this basal zone consists of angular 6-inch blocks of green and red Walnut Wells Monzonite, in a matrix of grayish blue tuff. A few equidimensional 7-inch granite cobbles weather out of this zone. In many areas the basal breccia is absent, and the andesite flow rock lies directly on quartz latite tuffs. In the SE1/4 sec. 27, T. 30 S., R. 18 W., there is a basal flow breccia which consists of large angular blocks of green andesite, generally 2 feet across, enclosed in green andesite. In the SW1/4 SW1/4 sec. 6, T. 31 S., R. 18 W., the basal zone consists of round spherules of green andesite, generally about 1 inch in diameter.

The andesite flow is typically green or red and commonly has green and red color bands. As seen in the field, the rock contains conspicuous plagioclase phenocrysts that are euhedral to subhedral, are gray, green, and red (hematitic), and measure up to 9 mm long and 5 mm in diameter, often about 3 mm by 1.5 mm or less. Also occurring are stubby pyroxene phenocrysts. Rarely occurring are euhedral brown biotite phenocrysts often about 2 mm across, and euhedral to subhedral clear sanidine phenocrysts often about 4 mm by 2 mm. Some green needle-like hornblende crystals are present. No quartz phenocrysts were observed. The bulk of the andesite is very dense, well indurated, and lacks gas cavities and planar structure. At the top of the flow at Cedar Hill, there is a black and green glass zone more than 15 feet thick above a vesicular zone. The glass zone contains angular andesite fragments up to a few inches across and has plagioclase and pyroxene phenocrysts. The andesite flow is free of foreign inclusions.

The Cedar Hill Andesite flow weathers to a rusty red. It is more resistant to erosion than the Basin Creek Tuff beneath, but much less resistant than the Gillespie Tuff above. The formation forms rounded, gently dipping slopes covered with platy angular blocks of andesite. Locally, soft andesite tuff is interbedded with the flows. The rock is essentially unaltered and unbrecciated. However, along the faults near the headwaters of South Thigpen Creek, and along the fault flanking the northwest side of the Animas range, the Cedar Hill Andesite is brecciated and locally silicified. Just west of Cedar Hill a few north-south trending minor faults contain fractures 0.25 to 1.5 inches wide filled with siderite and calcite veinlets. In a few places in sec. 18, T. 31 S., R. 18 W., the andesite has been epidotized along small fissures.

Two chemical analyses, norms, and the petrographic description of the Cedar Hill Andesite are recorded respectively in Tables 1, 2, and 7.

YOUNG RANCH TUFF

The Young Ranch Tuff is named for its limited occurrence near the Young Ranch. The formation rests unconformably upon the Cedar Hill Andesite west of the ranch and upon the U-Bar Formation and Timberlake Fanglomerate south of the ranch. On the northern flank of Horse Hill, the formation is overlain with apparent disconformity by the Gillespie Tuff.

Basal beds of the formation west of the Young Ranch consist of sandstone and limestone deposited in a lake. The sandstone consists of angular grains derived from the breakdown of a crystalline tuff. The limestone has fine wavy laminae, many of which are partly silicified. These sedimentary lake beds rest with disconformity upon the Cedar Hill Andesite.

The remainder of the formation is a columnar-jointed, flat-lying deposit at least 100 feet thick. It consists of welded tuff, tuff, and tuff-breccia and is of quartz latite composition. The rock is cream to light grayish brown, has crystals consisting mainly of feldspar and biotite, and has green flat lenses less than one inch long and a quarter of an inch thick. Toward the base, the deposit becomes more indurated and has such compaction characteristics as flattened lenses, fine streaks, which have been compressed around fragments, and an absence of gas cavities. The upper part is friable and lacks compaction features. The Young Ranch Tuff is probably equivalent to the Bluff Creek Formation, which it resembles in lithology and stratigraphic position.

Petrographic properties of the Young Ranch Tuff are shown in Table 8.

TABLE 7. PETROGRAPHIC DESCRIPTION OF THE CEDAR HILL ANDESITE

Percent phenocrysts: 35% average; 15-40% range

	Volume percentage	Average size (mm)	Shape	Color	Character
Phenocrysts					
plagioclase (An 40)	25	.70	euhedral	colorless	zoned; andesine-oligoclase saussuritization; glomeroporphyritic; corroded; Carlsbad and albite twinning
clinopyroxene	2 to 4	.40	euhedral to subhedral	light green non-pleochroic	corroded; magnetite alteration on rims and along cracks
biotite	1	.50	euhedral to subhedral	light brown	corroded; magnetite rims
K-Na feldspar (sanidine)	3 to 7	.60	euhedral to subhedral	colorless	altered slightly to clay minerals; zoned; Carlsbad twinning; low 2V; corroded
magnetite	2 to 4	.12	euhedral to anhedral	black	primary crystals and alteration of femic minerals
Accessory minerals					
zircon, apatite			euhedral to subhedral		commonly in phenocrysts
Alteration minerals					
clay	trace				alteration of feldspars
hematite	<2				alteration of magnetite; in cracks in rocks; common in red bands
sericite	trace				alteration of feldspars
Matrix	<.02 to .04				glassy to cryptocrystalline to aphanitic; plagioclase main mineral, some sanidine

Note: Some thin sections have minor amounts of hornblende and orthopyroxene besides clinopyroxene.

BLUFF CREEK FORMATION

The Bluff Creek Formation is named for its exposure near Bluff Creek in the southeastern part of the Walnut Wells quadrangle. The formation unconformably overlies the Timberlake Fanglomerate and it is overlain by the Gillespie Tuff with apparent conformity.

The Bluff Creek Formation lies south of Cowboy Spring and reaches a maximum thickness of about 1000 feet half a mile south of Bluff Creek. Individual units lens out toward the north; north of the Bluff Creek area

TABLE 8. PETROGRAPHIC DESCRIPTION OF THE YOUNG RANCH TUFF OF QUARTZ LATITE COMPOSITION

Percent coarse crystals: 35% average; 25-40% range

	Volume percentage	Size (mm)	Shape	Color	Character
Coarse crystals					
plagioclase (An 31)	15	<.20 to 1.60 .40 average	euhedral to subhedral	colorless	intensely corroded; fragmental; calcite alteration; Carlsbad and albite twinning
sanidine	10	<.20 to 2.00 .30 average	euhedral to subhedral	colorless	corroded; fragmental; altered occasionally to calcite; crystals sometimes grouped; Carlsbad twinning
quartz	7	<.20 to 1.50 .45 average	euhedral to subhedral	colorless	fragmental; rarely altered
biotite	3	<.20 to .85 .25 average	euhedral	brown	commonly only slightly corroded; rarely altered
magnetite	∼1	<.20 to .50 .25 average	euhedral to anhedral	black	in biotite and matrix
Accessory minerals					
zircon, apatite					
Alteration minerals					
calcite					alteration product of feldspars and matrix.
chlorite					alteration product of feldspars and matrix; and in oval nodules.
sericite, clay					alteration product of feldspars and matrix
Matrix	compaction fractures; spherulites; cryptocrystalline				

less than 6 units are present in this formation. The formation consists of beds of quartz-latitic pyroclastics interbedded with lenticular clastic sedimentary beds; foreign rock fragments are present in the pyroclastic rock. The beds weather differentially and dip toward the west. No fossils were found in the sedimentary units. A generalized partial stratigraphic section is given in the appendix.

GILLESPIE TUFF

The Gillespie Tuff, which is of quartz latite composition, is named for its exposures on Gillespie Mountain. It is the most prominent and widespread volcanic unit in the entire Walnut Wells quadrangle. In addition, it is one of the most persistent volcanic formations in the southwestern corner of New Mexico. Zeller (1962) recognized it in the other parts of the Animas Mountains west and south of the Walnut Wells quadrangle to the Mexican border. The formation extends into Mexico. An identical formation mapped by Zeller (1958) in the Alamo Hueco Mountains, which he called "coarse-grained quartz latite," is probably the Gillespie Tuff. Zeller also mapped an identical formation in the Peloncillo Mountains south of Antelope Pass.

In the Walnut Wells quadrangle the Gillespie Tuff is exposed in a broad southward-plunging faulted syncline with its northernmost exposures near the mouth of Bull Creek. The synclinal axis passes approximately through Gillespie Mountain where dips are southerly; from here westward and southwestward along the western limb dips are generally toward the southeast. From Gillespie Mountain southward and southeastward dips are generally toward the southwest. The formation has its greatest area of exposure from Cowboy Rim southward through the Walnut Creek drainage. The Gillespie Tuff has a thickness of more than 1500 feet in the quadrangle.

From the Cowboy Spring area northward the Gillespie Tuff rests with apparent conformity upon the Cedar Hill Andesite; to the south it lies with apparent conformity upon the Bluff Creek Formation. West of the Timberlake Ranch the Gillespie Tuff lies upon quartz latite tuff of the Bluff Creek Formation. Though the lithologies are similar, the quartz latite of the Gillespie Tuff, unlike that of the Bluff Creek, has no bedding planes and does not contain foreign rock fragments.

In the southern third of the quadrangle the formation is overlain disconformably by a unit of well-bedded sandstone and breccia up to 30 feet thick; some of the rock is red. Above this unit lies the Center Peak Latite which thins northward and is missing in the northern two-thirds of the quadrangle. In the northern part of the quadrangle the Park Tuff and its basal cream-colored tuffaceous sandstone member rest unconformably upon the Gillespie Tuff.

The Gillespie Tuff is an unusually thick welded tuff. Its most diagnostic features are as follows: it is massive, forms high mountains and cliffs, is columnar jointed, has lithic streaks, has abundant coarse quartz and feldspar crystals, and usually its fresh color is pink. It is remarkably uniform in color, texture, and weathering characteristics throughout its areal distribution and over most of its vertical extent. Except for the base, it lacks any noticeable indication of interrupted deposition.

The base of the formation generally consists of 0 to 25 feet of white, pink, or red tuff, occasionally with quartz and feldspar crystals about 1.5 mm in diameter. Above the thin layer of tuff is a black glassy zone, which contains numerous clear white, euhedral, lath-like sanidine crystals and subhedral to euhedral dipyramidal quartz crystals, usually 1 to 1.5 mm in diameter, and rarely 2 mm long. The glassy zone is usually about 35 feet thick but varies from 20 feet at the north part of Cowboy Rim to 120 feet at the southeast part of Cowboy Rim; it is present near or at the base of the Gillespie Tuff throughout the Walnut Wells quadrangle. In some areas the underlying tuff is absent, and the hyaline zone rests directly on the Cedar Hill Andesite or on the Bluff Creek Formation.

Over most of the quadrangle this glassy rock contains a large proportion of tightly compressed black glass lenses 3 to 35 mm long and 1 to 5 mm thick. Approximately half of the glass lenses and matrix consists of white or clear quartz and feldspar crystals. Wentworth and Williams (1932) classify this rock type as a crystal vitric tuff. South of the Cowboy Spring area the glassy zone is thicker and consists of tightly compressed black glass lenses, usually less than 8 mm long, and less than 1 mm thick, in a brown glass matrix. The lenses form planar structures, parallel to the layering of the welded tuff. The rock is about 30 percent quartz and feldspar crystals. The hyaline horizon has a minor amount of oval fragments of welded tuff approximately 10 mm in diameter. The glassy basal zone is characteristic of welded tuffs; heat was accumulated at the base of such masses, and fusion was more complete (Fenner, 1937, 1948; Marshall, 1935; Mansfield and Ross, 1935).

The main part of the exposed Gillespie Tuff has an extremely consistent and uniform pink color and is well indurated. Clear to grayish euhedral, subhedral, and dipyramidal quartz crystals up to 3 mm in diameter and clear, colorless, lath-like, euhedral feldspar crystals up to 4 mm long and 2.5 mm wide are the most common and characteristic crystals seen in this rock in the field. Brown and black pseudohexagonal biotite crystals up to 2 mm in diameter are also common. White, brown, and red lenses about 30 mm long, 10 mm wide, and 2 mm thick, are very noticeable. They have the same composition as the rest of the rock and may represent either compressed and collapsed cavities that have been lengthened by flow, or elongated lithic fragments. These lenses form planar structures. Small angular lithic fragments from 3 to 15 mm long are prevalent. No open gas cavities are present. The rock is very resistant to weathering and forms thick tabular masses, the eroded edges of which form almost vertical cliffs marked by broadly spaced columnar jointing. The rock weathers to a tannish pink and has manganese oxide stains along some fractures. Along high angle faults the rock is severely brecciated and in some places silicified.

At a locality on the northern part of Cowboy Rim in sec. 16, T. 31 S., R. 18 W., a 25-foot-thick zone of spherules lies on top of the basal black glassy zone. The spherules, about 18 mm in diameter, are filled with quartz. This zone pinches out to the east and west. Near this locality quartz veinlets fill fissures in the quartz latite of the Gillespie.

The lower part of the Gillespie Tuff in the vicinity of the Timberlake Ranch differs from the more typical quartz latite tuff of other parts of the formation. The matrix is whiter, crystals are less abundant and smaller, and there is very little biotite. These same characterisitics are found in the Gillespie Tuff along the western border of the quadrangle in sec. 11, T. 32 S., R. 19 W. and also west and southwest of the quadrangle boundaries.

A chemical analysis of the Gillespie Tuff is given in Table 1, its norm is given in Table 2, and its petrographic description is shown in Table 9.

The following characteristics suggest that the Gillespie Tuff is an ignimbrite: (1) great areal distribution; (2) sheet-like tabular body; (3) columnar jointing perpendicular to an almost horizontal cooling surface; (4) low primary dip of strata; (5) flattened lithic lenses; (6) glass zone at the base; (7) lack of flow banding, vesicular cavities, or foreign inclusions. Fenner (1948) and Moore (1934, p. 374) describe criteria for recognition of an ignimbrite.

CENTER PEAK LATITE

The Center Peak Latite is confined to the southwestern part of the quadrangle within a radius of several miles of Center Peak for which it is named. The rock, a hornblende latite, is conspicuous because of the abundance of black glossy needles of hornblende.

The Center Peak Latite rests unconformably upon the Gillespie Tuff. Commonly a thin bed of sandstone and breccia ranging in thickness from 0 to more than 30 feet lies at its base. The post-Gillespie erosion surface had considerable relief; in places the Gillespie Tuff was deeply eroded. Clastic beds at the base of the Center Peak Latite fill stream channels and other low areas on this erosion surface. In many places the latite rests directly upon the Gillespie Tuff.

The formation is overlain unconformably by the Park Tuff, the sandstone member of the Park Tuff, and the OK Bar Conglomerate. Erosion after deposition of the Center Peak Latite cut deeply into the hornblende latite and earlier rocks, and the relationships between the formations that lie upon this surface are complex. These relationships are described later.

The formation has its maximum thickness (about 1000 feet) between Center Peak and a point about 2 miles to the south. It thins in all directions from this area, partly because of post-Center Peak Latite erosion, and probably partly because of increasing distance from the source area. The formation pinches out about 21/2 miles north and 2 miles west of Center Peak. East and southeast of Center Peak the formation has been removed by recent erosion.

Flow breccia is present in most places at the base of the formation. This breccia consists of angular hornblende latite fragments from 2 inches to 3 feet in diameter in a matrix of hornblende latite. In one locality, in sec. 29, T. 31 S., R. 18 W., the basal flow breccia is oxidized and has a red color. In sec. 8, T. 32 S., R. 18 W., a 25-foot thick vesicular

TABLE 9. PETROGRAPHIC DESCRIPTION OF THE GILLESPIE TUFF OF QUARTZ LATITE COMPOSITION

Percent coarse crystals: 40% average; 20-55% range

	Volume percentage	Average size (mm)	Shape	Color	Character
Coarse crystals					
quartz	7 to 10	.90	euhedral to subhedral	colorless	corroded slightly on edges; some twinning; strained; broken
sanidine	15	.75	euhedral to subhedral	colorless	aggregates of crystals; zoned; partially corroded; Carlsbad twinning; broken
plagioclase (An 28)	12	.60	euhedral to subhedral	colorless	corroded; Carlsbad and albite twinning; broken.
biotite	1 to 2	.55	euhedral to subhedral	brown	corroded; included in plagioclase; includes magnetite; magnetite rims
magnetite hematite	1 to 2	.20	euhedral to subhedral	black	included in biotite; and rims biotite; in matrix also
Accessory minerals					
zircon and apatite					in megascopic crystals and in matrix
Matrix					
glassy to cryptocrystalline (some thin sections partially devitrified and fine grained); compaction features common; limonitic staining is common and intense					

Note: Hornblende is indicated in some thin sections though completely altered to magnetite and fine grained matrix.
Some thin sections have almost twice as many sanidine crystals as plagioclase.

and amygdaloidal basal zone occurs; the amygdules in this zone are from less than an inch to 3 inches long and are composed of fine-banded white to pink chalcedony.

The bulk of the Center Peak Latite, which lies upon the basal flow breccia, consists of a hornblende latite. Its outstanding megascopic feature is the abundance of euhedral and subhedral hornblende phenocrysts 2 to 4 mm long. These phenocrysts are needle-shaped, black, gray and red, and are conspicuous against the light background of the matrix. White, chalky, subhedral and euhedral feldspar phenocrysts about 2 mm long are also commonly seen megascopically. Euhedral and subhedral clear quartz phenocrysts are present in minor amounts in a few places, but usually quartz and biotite phenocrysts are absent. The rock is well indurated, generally massive, and devoid of streaks, lenses, cavities, and xenoliths, although it sometimes has fine gray flow streaks about 25 mm long and 2 mm wide, which are spaced about 1 to 5 mm apart. It weathers to a grayish cream color. The formation weathers into dome-shaped masses and forms rounded, gently inclined slopes. It lacks columnar jointing and is not brecciated above the basal zone.

Petrographic description of the Center Peak Latite is given in Table 10.

The source area is probably in the vicinity of Center Peak where the formation attains its greatest thickness; northward and westward from Center Peak, the formation becomes thinner. The following evidence suggests that the latite formation is a flow: (1) limited distribution; (2) rapid thinning from more than 1000 feet to less than 100 feet within a radius of 2 miles; (3) fine flow bands in some parts; (4) vesicular and amygdaloidal base; (5) flow breccia at base; (6) top part of formation, where observed, has thin quartz veinlets and is more porous than the rest of the formation; and (7) lack of bedding.

PARK TUFF

The Park Tuff is named from its exposures around the rim of the Park (fig. 3); because of its white color the field term used was "white tuff." Within the quadrangle the Park Tuff has scattered exposures in the western half of the Animas Mountains from Bull Creek to the southern border of the quadrangle, and it extends west and southwest into the adjacent quadrangles (Zeller, 1962). The formation is a thin sheet of tuff that was deposited over most if not all of the quadrangle. It commonly forms the tops of flat-topped or gently sloping mesas.

This formation is relatively thin and consists of a basal sandstone member from 20 to 100 feet thick and an overlying bed of uniform white rhyolite tuff ranging from 0 to nearly 300 feet thick. The Park Tuff rests upon an erosion surface cut into Center Peak Latite, Gillespie Tuff, and Cedar Hill Andesite. It is overlain by OK Bar Conglomerate in most areas, but along the northern part of Double Adobe Creek it is overlain by Double Adobe Latite. Near Forest Camp in the southwestern part of the quadrangle the tuff bed thins and wedges out and the OK Bar Conglomerate rests upon the sandstone member; farther south the sandstone member is not recognized and is probably missing.

The tabular bed of white rhyolite tuff is very uniform vertically and laterally, and it is characterized by its white to light gray color. It contains numerous euhedral iridescent crystals of sanidine about 1 mm in size, and euhedral and subhedral, triangular, clear quartz crystals about .5 mm in diameter. Euhedral bronze biotite flakes approximately .2 mm across are present in minor amounts. The rock is well indurated.

White pumaceous lenses are very common throughout the rock. They are usually about 25 mm long, 15 mm wide, and 5 mm thick, and rarely reach a size of 80 mm long, 50 mm wide, and 25 mm thick. The lenses are planar structures that are generally parallel to bedding. The

TABLE 10. PETROGRAPHIC DESCRIPTION OF THE CENTER PEAK LATITE

Percent phenocrysts: 60% average; 50-70% range

	Volume percentage	Average size (mm)	Shape	Color	Character
Phenocrysts					
plagioclase (An 32)	36	.3 to .6	euhedral	colorless	uniform size; thin laths; trachytic; Carlsbad and albite twinning
sanidine	16		euhedral to subhedral	colorless	zoned; corroded; stubby; Carlsbad twinning; incipient replacement by matrix
quartz	<2		euhedral	colorless	clear; unaltered; wavy extinction
hornblende	6 (3 to 15 range)		euhedral and subhedral	green	pleochroic; reddish brown to green; partly to completely oxidized and replaced by matrix; twins
Accessory minerals					
zircon, apatite, magnetite					very rare
Matrix	crytocrystalline to fine-grained; mainly plagioclase and sanidine; some quartz; shows flow orientation of phenocrysts in matrix.				

Note: No biotite; plagioclase did not reach equilibrium conditions; plagioclase from An 28 to An 38 present.

tuff is free of cavities except locally at the base and top. Xenoliths are lacking except locally at the base. The rock weathers dull gray and cream and forms resistant flat tabular sheets, the eroded edges of which are almost vertical cliffs. In some places the formation has conspicuous columnar jointing. The columns are a few feet in diameter and tens of feet in length, and they are often octagonal in cross section. Where columnar jointing is prevalent, talus deposits at the base of the outcrop are composed of columnar blocks.

The following characteristics show that the tuff is welded: (1) large areal distribution; (2) sheet-like bed; (3) columnar jointing perpendicular to an almost horizontal cooling surface; (4) flattened lithic lenses; (5) lack of foreign inclusions; (6) deformed shards; and (7) recrystallized matrix.

Chemical composition, norms, and petrographic description of the Park Tuff are shown in Tables 1, 2, and 11, respectively.

TABLE 11. PETROGRAPHIC DESCRIPTION OF THE PARK TUFF OF RHYOLITE COMPOSITION

Percent coarse crystals: 15% average; 12-20% range

	Volume percentage	Average size (mm)	Shape	Color	Character
Coarse crystals					
sanidine	9	1.00	euhedral to subhedral	colorless	corroded; fractured; fresh; unsorted; Carlsbad twins
quartz	5	.60	euhedral to subhedral	colorless	corroded; fractured; fresh; fragmental
biotite	<1	.20	euhedral to subhedral	reddish	corroded; reaction rim around magnetite
magnetite	<1	.30	subhedral to anhedral	black	rims sphene; minor amount in matrix
sphene	<1	.30	subhedral	yellowish	slightly pleochroic; rim of magnetite around sphene, and rim of biotite around magnetite
Accessory minerals					
zircon					associated with the sphene in feldspars
Matrix					
glassy-cryptocrystalline shards; deformed shards; recrystallized					

Note: No Plagioclase; no foreign fragments.

OK BAR CONGLOMERATE

The OK Bar Conglomerate is named for OK Bar Camp where the formation, predominantly conglomerate, is well exposed. In the Walnut Wells quadrangle the formation is exposed only in the southwestern part, but it extends west, southwest, and south beyond the limits of the quadrangle (Zeller, 1962).

The OK Bar Conglomerate rests upon the Park Tuff throughout most of the area, but along the southern stretch of Deer Creek in secs. 19, 20, 29, and 30, T. 32 S., R. 18 W., the formation rests upon Center Peak Latite.

The OK Bar Conglomerate is the youngest Tertiary formation exposed in the extreme southwestern corner of the quadrangle. West of Double Adobe Creek, the Double Adobe Latite and the Pine Canyon Formation rest upon part of the conglomerate. South of this area, from the vicinity of Forest Camp to the southwestern corner of the quadrangle, the OK Bar Conglomerate is composed largely of detritus derived from the Pine Canyon Formation, and therefore this part of the conglomerate formation must be younger than the Pine Canyon Formation. Thus, deposition of the conglomerate started before extrusion of the Pine Canyon Formation and the equivalent Double Adobe Latite, and this deposition continued for some time after the extrusion of these volcanic formations. Southwest of the quadrangle the OK Bar Conglomerate is overlain with sharp angular unconformity by younger basalt or andesite flows and pyroclastic beds. South of the quadrangle, in the Deer Creek drainage, Quaternary gravels, which are chiefly derived from the conglomerate formation, rest unconformably upon the OK Bar Conglomerate; it is sometimes difficult to distinguish between the two.

The thickness of the formation varies from 0 feet near the mouth of Wolf Canyon where Double Adobe Latite rests upon the Park Tuff to several hundred feet in the southwest corner of the quadrangle. The basal part of the formation was deposited largely in canyons and other depressions in the pre-OK Bar Conglomerate erosion surface, and the upper part was deposited in basins and as alluvial fans.

Pre-OK Bar Conglomerate erosion cut deep canyons in the Center Peak Latite southwest of Center Peak. Sand, gravel, and angular boulders eroded from the latite were deposited in horizontal strata in these steep-walled canyons. The latite of these deposits is fresher in appearance than recently weathered latite, a fact indicating that pre-OK Bar erosion was deep enough to have cut into fresh bedrock. Recent erosion favored these earlier canyons and caused much of the pre-OK Bar surface to be exhumed.

In this same area, canyon filling was followed by the deposition of alluvial fans; detritus in the lower beds consist entirely of Center Peak Latite. Higher beds in the fans, which are interfingered near Deer Creek with deposits from the west, have a mixture of detritus derived from Center Peak Latite and from the Pine Canyon Formation. West of the Deer Creek area, this mixture of detritus is overlain by a thick deposit of gravel derived almost entirely from the Pine Canyon Formation with no Center Peak Lathe detritus present.

North of Center Peak Alper found that the formation has two facies, one deposited in steep-sided narrow canyons and one deposited in shallow wide basins cut into Gillespie Tuff and Park Tuff in the vicinity of OK Bar Camp.

The part of the OK Bar Conglomerate deposited in the canyons is an unsorted breccia. The breccia consists of angular fragments derived mainly from Park Tuff and partly from Gillespie Tuff. These fragments vary in size from less than an inch to a foot or more in diameter and are cemented in an arkosic sandstone matrix. The sandstone is made up of many euhedral and subhedral glassy quartz grains and also contains euhedral and subhedral iridescent and clear sanidine rectangular prisms a few millimeters long. These grains were derived from the underlying formations where they once existed as coarse crystals. The retention of the original euhedral and subhedral shapes of the grains indicates that they were not transported far. The angular nature of the fragments, the lack of sorting, and the euhedral and subhedral grains of the matrix are evidence that this part of the formation was an ancient talus deposit. The canyon-deposited breccia occurs as large wedge-shaped deposits which are a few hundred yards long, zero to a few hundred feet wide, and about 50 feet thick. The present stream channels often follow these late Tertiary canyon deposits.

The part of the OK Bar Conglomerate that occupied wide basins has a different lithology. A basal conglomerate zone consists chiefly of rounded boulders of Park Tuff and some Gillespie Tuff, most of which are less than 8 inches across. From the conglomeratic zone upward, successive strata have gradually smaller rounded fragments. In the upper 45 feet of the formation the matrix becomes finer and consists of uniform, well-sorted, thin-bedded, medium- to fine-grained, friable, white to pink sandstone and tuffaceous sandstone with green specks and thin gypsum layers. In the basins the formation was water-lain and the boulders were transported from exposed hills. The detritus of the formation becomes coarser and the boulders become more angular close to the erosional highs on the underlying surface.

PINE CANYON FORMATION

This formation is named for Pine Canyon near which it is well exposed; it is evidently a flow of latitic composition.

Originally the authors interpreted this formation as an upper flow facies of the Park Tuff. This opinion was formed on the basis of the similar appearance of the two formations, and their similar relationship to other formations; therefore they mapped it with the Park Tuff. After termination of the mapping in the quadrangle, Zeller studied the area west of the quadrangle and found relationships which led to the hypothesis that the formation has a different stratigraphic position than the Park Tuff. Close field checking in the Bear Canyon area confirmed this hypothesis and proved that this formation is intertongued with and equivalent to the Double Adobe Latite. The authors did not have an opportunity to return to the field to study and map the formation. Therefore, they wrote the following description of the formation on scant field data and no laboratory information, and they sketched a surmised distribution of the formation on the geologic map (pl. 1) without the aid of aerial photographs. On the map the Pine Canyon Formation and associated formations in the same area are shown with "doubtful or probable" contacts.

The Pine Canyon Formation is intertongued with the Double Adobe Latite in Bear Canyon in section 23, and in sections 25 and 26, all in T. 31 S., R. 19 W., and also west of the quadrangle boundary. The Pine Canyon Formation rests upon a moderate thickness of OK Bar Conglomerate in this area, and the lower beds of both the Pine Canyon Formation and the Double Adobe Latite are interbedded with a conglomerate similar to the OK Bar Conglomerate. As mentioned, west of Deer Creek the upper part of the OK Bar Conglomerate consists mostly of detritus derived from the Pine Canyon Formation. Therefore, deposition of the OK Bar Conglomerate started before extrusion of the Pine Canyon and Double Adobe units and continued after their extrusion. These relationships are shown schematically in Figure 5.

The composition of the Pine Canyon Formation was not studied, but its rock appears to be latite. Flow bands, which are often 2 to 4 inches apart and which are sometimes contorted, and flow breccia and agglomerate indicate that the formation is of flow origin; sharp differences in rock textures and in attitudes of flow bands suggest that the formation may represent a composite flow. The source area of the flows apparently was in the headwaters area of Pine Canyon where flow planes are quite contorted and have steep attitudes, and where the formation attains its greatest thickness of at least several hundred feet. Here the formation weathers into high prominent white pinnacles.

South and east of the headwaters area of Pine Canyon the formation has been removed by erosion. The Pine Canyon Formation thins rapidly, toward the north where it is intertongued with the Double Adobe Latite. West of Adobe Creek Well, where these beds are intertongued with the Double Adobe Latite, the rock consists largely of porous and banded flow breccia and agglomerate. Here planar flow structures dip sharply northward and rest upon a nearly horizontal sandstone of the OK Bar Conglomerate.

DOUBLE ADOBE LATITE

The Double Adobe Latite is named for Double Adobe Creek which flows along most of the northeastern boundary of the formation. The formation is exposed in the westernmost part of the Walnut Wells quadrangle in T. 31 S., R. 19 W., and extends westward into the Animas Peak quadrangle (Zeller, 1962).

This formation and its equivalent, the Pine Canyon Formation, are the youngest extrusive units in the quadrangle. The tops of these two formations are not exposed. As mentioned, some of the OK Bar Conglomerate south of the exposures of Double Adobe Latite and Pine Canyon Formation is younger than the extrusives, but that conglomerate is not in contact with the latite. The Double Adobe Latite rests upon the Park Tuff, upon tongues of the Pine Canyon Formation, and upon basal OK Bar Conglomerate. In Bear Canyon, the lowermost part of the Double Adobe Latite rests upon OK Bar Conglomerate and is interbedded with a tongue of Pine Canyon Formation (fig. 5). The Double Adobe Latite is younger than Park Tuff and the basal OK Bar Conglomerate; the basal beds are interbedded with, and are consequently the same age as, the Pine Canyon Formation and some OK Bar Conglomerate.

Approximately 900 feet of Double Adobe Latite is exposed in the quadrangle and more than 1000 feet appears to be exposed in the neighboring Animas Peak quadrangle to the west. The formation apparently consists of an ill-defined series of latite flows. Each individual flow has a vesicular tuffaceous oxidized base which grades upward into massive latite free from cavities; this grades upwards into a vesicular top. In places the cavities are filled with clear crystalline quartz. The latite is usually dark gray to dark purple but in places is brown, red, or greenish yellow. It contains many euhedral and subhedral glassy white or green plagioclase phenocrysts up to 9 mm long and 4 mm wide, though usually about 4 mm by 2.4 mm or smaller. Green stubby ferromagnesian crystals, about 1 mm long, and metallic oxides occasionally are enclosed by the phenocrysts. The matrix varies in texture from dense, massive, and cherty, to spherulitic; purple spherulites 2 mm in diameter are surrounded by dark, thin, flow bands (0.5 mm thick). The rock is well indurated, lacks xenoliths and lenses, and is vesicular only at the top and bottom of individual flows. The rock weathers rusty, and its surface is marked by many small (4 mm) rectangular cavities due to weathering out of less resistant plagioclase phenocrysts.

The formation is not resistant to weathering and forms rounded, gentle slopes covered by small (1.5 ft. or less), platy, angular blocks of latite. In places curved joints are common in the formation.

Chemical composition, norms, and petrographic description of the Double Adobe Latite are given in Tables 1, 2, and 12.

QUARTZ LATITE DIKES

East of the Gillespie mine dikes of quartz latite porphyry strike northeastward and dip steeply. They lie en echelon and parallel to a large post-Cretaceous fault. The intrusion of a dike into the fault zone shows that the quartz latite was emplaced after movement of the fault. Flow laminae are contorted and nearly vertical. The intrusive nature of the rock may be seen best in the westernmost pulley that cuts the dikes.

OLIVINE ANDESITE LENTICULAR INTRUSION

An olivine andesite mass intruded the Gillespie Tuff and the Park Tuff in sec. 36, T. 31 S., R. 19 W. The intrusive body is about 350 feet

TABLE 12. PETROGRAPHIC DESCRIPTION OF THE DOUBLE ADOBE LATITE

Percent phenocrysts: 16% average; 10-20% range

	Volume percentage	Average size (mm)	Shape	Color	Character
Phenocrysts					
plagioclase (An 29)	6	.60	euhedral to subhedral	colorless	minor albite and pericline twinning; albite and Carlsbad twinning; glomeroporphyritic; corroded
quartz	2	.80	euhedral to anhedral	colorless	glomeroporphyritic; corroded; some fractured
sanidine	7	.70	euhedral to subhedral	colorless	glomeroporphyritic; zone corroded
biotite	1	.45	euhedral	brown	associated with magnetite
pyroxene (clinopyroxene)	<1 to 2	.25	subhedral	colorless	corroded and altered; commonly at centers of crystal clusters
magnetite	<1	.20	euhedral to anhedral	black	rarely included in plagioclase; alters to hematite and limonite; commonly in matrix
Accessory minerals					
zircon and apatite					in groundmass and in phenocrysts
Matrix					
glassy to cryptocrystalline; flow banding is common					

in diameter and 35 feet thick. The rock is black with tiny gray and brown specks, is very dense, weathers yellow-brown, and contains xenoliths from the Gillespie Tuff and the Park Tuff.

Microscopic examination reveals that 48 percent of the andesite is made up of microphenocrysts, which are generally less than .15 mm long, though they rarely are as large as 1.20 mm. Most of these microphenocrysts are euhedral to subhedral; they are contained in a black cryptocrystalline-to-glassy matrix. The andesite consists of 36 percent plagioclase (An 42) microliter, 5 percent olivine (red iddingsite rims), 5 percent clinopyroxene, 2 percent magnetite, and 1 percent orthopyroxene. The texture of the rock is hyalophitic, a term used by Williams, Turner, and Gilbert (1954, p. 22).

Within 6 mm of the contacts, rhyolite xenoliths have been altered by the andesite. Some femic microphenocrysts have replaced the matrix of the rhyolite. Corroded, rhyolitic, island-like, remnant structures are embayed by the andesite. The andesite also contains some xenocrysts of corroded quartz and sanidine.

The olivine andesite is younger than other intrusives in the quadrangle and younger than the Park Tuff. Its relation to the Double Adobe Latite is unknown.

SUMMARY OF IGNEOUS PHASES

Over 90 percent of the bedrock area of the Walnut Wells quadrangle consists of Tertiary extrusive and shallow intrusive rocks. Approximately 90 percent of the exposed igneous rocks are silicic to intermediate (rhyolite through latite).

Field and laboratory data indicate that there were four main igneous phases in this area. The first phase consisted of the extrusion of mainly quartz latite along with intrusion of its coarser-grained equivalent. This phase started with the deposition of the quartz latite of the Bennett Creek Breccia, continued with the deposition of the Cedar Hill Andesite, and ended with the deposition of the quartz latite of the Gillespie Tuff. An aggregate thickness in excess of 5000 feet was extruded and two monzonitic intrusions were emplaced.

A significant period of erosion was followed by the second igneous phase during which more than 1900 feet of the Center Peak Latite and the rhyolite of the Park Tuff was extruded.

The second phase was followed by another significant period of erosion. Subsequently, more than 1000 feet of Double Adobe Latite and Pine Canyon Formation was deposited during the third igneous phase.

Deformation and erosion were followed by deposition of andesite and basalt unconformably upon older rocks southwest of the Walnut Wells quadrangle. The olivine andesite was probably intruded during this fourth phase. Elevation and erosion of the Animas Mountains followed.

Quaternary Deposits

PEDIMENT GRAVEL

Thin remnants of pediment gravel are found resting upon erosionally beveled bedrock in the vicinity of Young Ranch on the eastern flank of the Animas Mountains. The gravel is unconsolidated and consists mainly of subangular to rounded boulders and cobbles derived mostly from Tertiary igneous formations and partly from Cretaceous sedimentary formations. Cobbles of Paleozoic limestone occur in minor amounts. Recent stream erosion has removed most of the pediment gravels and left linear remnants parallel to the drainage. These deposits are generally less than 75 feet thick.

ALLUVIUM

Stream gravels along the main drainages are commonly stratified with alternate layers of fine and coarse material. A few of the creeks were entrenched within these deposits.

Schwennesen (1918) described the valley fill. Because the topography of the bedrock is irregular, the fill varies in thickness. Well logs (Herbert Young, oral communication, 1955) show that about 3 miles east of Horse Hill the fill is only 20 feet thick and that it is 90 feet thick three quarters of a mile east of Red Hill mine. Irrigation wells drilled about 6 miles west of the Young Ranch penetrated to a depth of about 1000 feet without encountering bedrock. In contrast, in Animas Valley near the manganese mine, fill is more than 650 feet thick within 500 feet of a bedrock outcrop (data from the log of manganese mill well). Thus the Playas Valley fill is very thin for at least 3 miles east of the part of the Animas Mountains that lies in the Walnut Wells quadrangle, whereas the Animas Valley fill increases abruptly in thickness westward from the range. Lasky (1947) listed two wells drilled in the central part of the Playas Valley; these wells were said to be 836 feet deep and 1000 to 1100 feet deep, and neither reached bedrock. Lake deposits in the northeastern part of the Walnut Wells quadrangle are associated with the intermittent Playas Lake which extends into the Playas quadrangle to the north. The lacustrine deposits have been described by Schwennesen (1918).

Zircon Petrology

Zircons from the intrusive and some of the extrusive rocks were studied to further clarify the relationship among these rocks. Alper and Poldervaart (1957) published a detailed report on this study. A summary of the results of that investigation is given here.

Zircons were studied by measurement of lengths and widths of 200 crystals for each sample. The elongation (length/width), the mean length, and the mean width of the zircons were analyzed statistically. A mathematical comparison was made between the zircons from the quartz monzonite porphyry of the Animas stock, the quartz latite of the Oak Creek Tuff, the monzonite porphyry of the Walnut Wells plug, the rhyolite of the Park Tuff, and xenoliths encased by the intrusions.

Zircons from the Animas stock, the Oak Creek Tuff, and the Walnut Wells plug were found to be statistically the same. Zircons from granitic xenoliths occurring in the Animas stock and the Walnut Wells plug were different from the zircons of the host rocks. Zircons from the Park Tuff were different from those of the Animas stock, the rock of the Walnut Wells plug, and the Oak Creek Tuff. The uniformity of zircons from the stock, the Oak Creek Tuff, and the plug suggests that the rocks of each were derived from the same parent magma. The granitic xenoliths were foreign and not related to the enclosing rocks. The young Park Tuff, as indicated by field evidence as well as zircon data, was deposited during a different magmatic interval from the one in which the Animas stock, the Oak Creek Tuff, and the Walnut Wells plug were formed.

Exclusive of zircon studies, an intimate relationship between the Animas stock and the Oak Creek Tuff was established by field and laboratory evidence listed on page 34.

Field evidence indicates that the rock of the Walnut Wells plug was emplaced after the Oak Creek Tuff and before the Cedar Hill Andesite and Gillespie Tuff. Consequently, it was emplaced at approximately the same time as the Animas stock. Chemical compositions, calculated mineral norms (C.I.P.W.), and mineral compositions, all of which are listed in Table 14, and differentiation indices, which are shown in Table 2, show that this plug rock is slightly more mafic than the Animas stock and the Oak Creek Tuff.

Since the statistics of zircon measurements can be used as identifying characteristics of extrusives and intrusives, there is a possibility that in the future they will be used in the correlation of volcanic formations and in distinguishing derivatives of one magma from those of magmas of different ages.

TABLE 14.

SIMILARITY OF THE ANIMAS QUARTZ MONZONITE, THE OAK CREEK TUFF, AND THE WALNUT WELLS MONZONITE INDICATED BY CHEMICAL ANALYSES, C.I.P.W. MINERAL NORMS, AND MODES.

Chemical Analyses

Sample nos.*	A6	707	14	3
SiO_2	66.08	63.47	64.73	61.15
TiO_2	0.59	0.69	0.60	0.77
Al_2O_3	12.23	16.95	17.40	18.19
Fe_2O_3	7.40	3.08	3.64	3.69
FeO	0.71	1.56	0.36	0.92
MnO	0.06	0.07	0.03	0.05
MgO	1.31	1.73	1.17	1.84
CaO	2.52	3.70	1.91	3.46
Na_2O	3.85	3.94	3.85	4.07
K_2O	3.95	3.65	4.14	3.45
P_2O_5	0.11	0.10	0.17	0.15
H_2O+	0.62	0.75	1.61	1.46
H_2O-	0.21	0.20	0.58	0.66
CO_2	0.34	0.16	0.00	0.00
Total	99.98	100.05	100.19	99.86

(Chemical analyses by
H. G. Wiik, Helsinki, Finland)

Norms

Sample nos.*	A6	707	14	3
quartz	23.68	16.64	21.03	14.18
orthoclase	23.38	21.71	24.49	20.60
albite	32.52	33.57	32.52	34.62
anorthite	4.45	16.41	8.62	16.41
corundum	—	0.41	3.47	1.63
wollastonite	2.09	—	—	—
enstatite	3.21	4.32	2.91	4.62
ferrosilite	—	—	—	—
magnetite	0.93	3.24	—	.93
ilmenite	1.06	1.37	0.76	1.52
apatite	0.33	0.33	0.33	0.33
hematite	6.71	0.80	3.67	3.03
rutile	—	—	0.24	—
titanite	—	—	—	—
calcite	0.80	0.40	—	—
water	0.83	0.95	2.19	2.12
Totals	99.99	100.15	100.23	99.99
C.I.P.W. class.	I 423	I 423	I 423	I 424

Modes (volume percentage)

	Animas Quartz Monzonite	Oak Creek Tuff	Walnut Wells Monzonite
Phenocrysts			
plagioclase	29 (An 30)	16 (An 30)	16 (An 33)
K-Na feldspar	13	10	10
quartz	5	8	—
clinopyroxene	0-2	trace	2
biotite	1-2	1-2	2
hornblende	trace	<1	—
Matrix			
plagioclase	1-3	glassy to crypto-crystalline	19
orthoclase	20		30
quartz	20		18

* Sample numbers:
A6, 707 Animas Quartz Monzonite
14 Oak Creek Tuff (quartz latite)
3 Walnut Wells Monzonite

Structure

The rocks of the Walnut Wells quadrangle, which range in age from Permian to Recent, were involved in four periods of structural deformation. Geologic structures are described below under the periods of deformation during which they were formed.

The Winkler anticline displays the records of several periods of structural activity. Because this structure is so instructive and is referred to so often, it is described briefly prior to discussion of the periods of deformation.

WINKLER ANTICLINE

The Winkler anticline is named for Winkler Ranch, which at present is a camp on the Young Ranch. Folding of the structure since Tertiary deposition enabled deep erosion of Tertiary rocks; this erosion exposed the anticlinal core of older rocks in an inlier southwest of the Winkler Ranch. Proper interpretation of the anticline is fundamental to an understanding of the structural geology of the quadrangle and, indeed, is important to an understanding of the tectonics of the entire region.

The axial plane of the anticline strikes northeast; the axis plunges in both northeast and southwest directions as in an elongated dome. A structure contour map would show that the anticline has considerable closure. Near the structurally high part of the axis resistant Horquilla Limestone is exposed. The Horquilla is encircled by concentric bands of successively younger formations—Earp Formation, Colina Limestone, Hell-to-Finish Formation, U-Bar Formation, Mojado Formation, and Tertiary formations. Outcrop patterns of the exposed formations are complicated by a major unconformity at the base of the Cretaceous section and by a series of northeast-striking faults. Several high angle faults removed parts of the geologic section on the northwestern limb of the structure; the southeastern limb, though also faulted, may be traced. for about 4 miles from the axis by scattered exposures of Cretaceous rocks (pl. 1).

Two factors in the development of the anticline are of particular significance to the tectonic history of the region. First, the structure started its growth between middle Permian (Leonard) and Early Cretaceous time. Although such a period of deformation is known in southeastern Arizona, this is the first recognition of folding and faulting during this orogeny in southwestern New Mexico. Second, the structure continued its growth during and after deposition of the Tertiary rocks. This is the only structure known in southwestern New Mexico where a clear correlation is seen between folding in Tertiary rocks and earlier folding in underlying pre-Tertiary rocks. Thus, development of the structure started early, continued through several periods of deformation, and ended late. This development is shown in section AA', Plate 2, in which the stages of growth of the anticline are indicated by the angular unconformities at the bases of the Cretaceous and Tertiary sections and are further shown by the folding of Tertiary rocks into a gentle anticline upon the parent structure. Details of the development of the anticline are described below under the various periods of deformation.

PERIODS OF DEFORMATION

Crustal deformation of the rocks exposed in this quadrangle occurred during four periods. The earliest involved Permian rocks of Leonard age but not rocks of Early Cretaceous age, and it is described under the heading "Deformation later than Leonard deposition and earlier than Early Cretaceous deposition." The second, and strongest period of deformation, involved pre-Tertiary rocks and is described under the heading "Deformation later than Early Cretaceous deposition and earlier than Tertiary deposition." The third involves parts of the Tertiary section and is described under the heading "Deformation during Tertiary deposition." The last involved all of the Tertiary rocks in the area and is described under the heading "Deformation after Tertiary deposition."

DEFORMATION LATER THAN LEONARD DEPOSITION AND EARLIER THAN EARLY CRETACEOUS DEPOSITION

Early folding of the Winkler anticline occurred between Permian and Cretaceous time. This folding of the anticline is indicated by the absence of several thousand feet of the upper Permian rocks beneath the Cretaceous section on the anticline. These Permian rocks, though present nearby, were eroded from the anticline as the structure arched upward prior to Cretaceous deposition. The evidence follows.

On three sides of the Winkler anticline the erosional unconformity at the base of the Cretaceous section rests upon the lower part of the Colina Limestone; on the east end of the anticline it rests upon the upper beds of the Earp Formation, the Colina Limestone here having been removed by erosion (pl. 1 and section AA' of pl. 2). In the Big Hatchet Mountains the section below the basal Cretaceous unconformity includes the Earp Formation, Colina Limestone, Epitaph Dolomite, Scherrer Formation, and Concha Limestone; elsewhere in the region a great thickness of post-Earp Permian formations also is found below the unconformity. The Concha Limestone and the underlying Epitaph Dolomite were originally present in the area of the Winkler anticline; this is shown by the exposure of Concha Limestone one mile east of the Young Ranch and also by the inclusion of tremendous boulders of Concha Limestone and Epitaph Dolomite in a limestone conglomerate within the lower formation of the Tertiary volcanic section only 4 miles northeast of the anticline (p. 12). The great size of these boulders indicates a nearby source. The stratigraphic thicknesses of missing Permian strata, as determined by measurements in the nearby Big Hatchet Mountains (Zeller, 1965), is between 2800 and 3200 feet. This anomalous removal of section was due to growth of the anticline during the time interval between deposition of the Colina Limestone (Leonard) and the lowermost beds of the Cretaceous section (Trinity or slightly older); as the area was domed upward, erosion cut away the elevated rocks.

Another bit of evidence for this early growth of the anticline is the angular nature of the unconformity at the base of the Cretaceous section. This is not obvious on the contact in the field, but on the geologic map (pl. 1) it can be seen that the attitudes of the beds under the unconformity are generally steeper than those of the overyling Cretaceous beds.

Evidence from two faults shows that some faulting occurred on the Winkler anticline prior to Cretaceous deposition. One of the faults, a small one that strikes northeast, lies along the northwest side of the small conical hill east of the center of sec. 3, T. 31 S., R. 18 W. The fault and its development are illustrated in Figure 9. On the northwest side

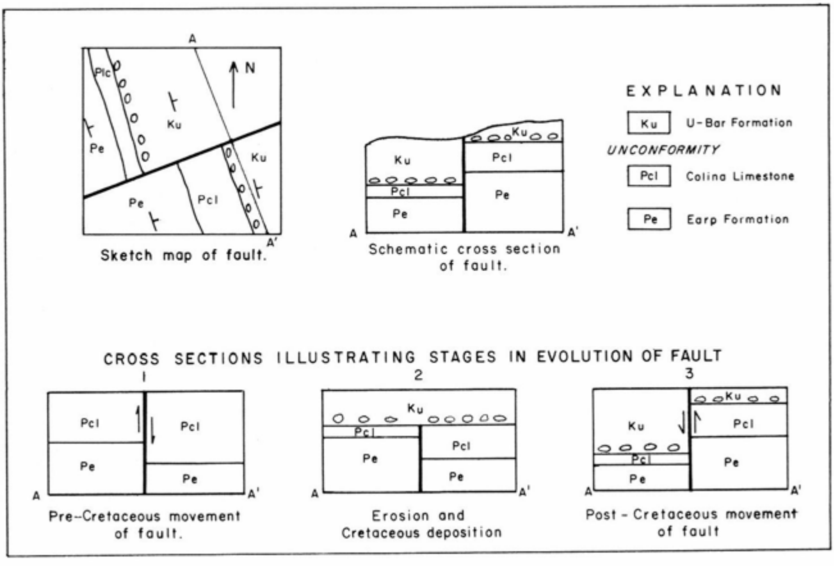


Figure 9

PRE-CRETACEOUS AND POST-CRETACEOUS MOVEMENTS OF SMALL FAULT

Location east of center of sec. 3, T. 31 S., R. 18 W.

the fault beneath a peculiarly shaped, elongated and narrow exposure.

The presence of the fault below the Cretaceous beds is indicated by the thinness of the Earp Formation here. Though little of the Earp is exposed due to the Cretaceous cover, the space between the Horquilla and Colina which would be occupied by the Earp is so narrow that only a fraction of the Earp Formation could be present. Therefore, the fault must have moved before Cretaceous deposition and displaced most of the Earp.

After movement of the fault, erosion cut deeply and carved a long narrow valley in the soft Earp Formation along the fault. Cretaceous deposits then blanketed the area. Recent erosion removed nearly all of the Cretaceous blanket, leaving only the part that occupied the narrow valley, and several thin remnants on the Colina spur. Minor post-Cretaceous movement of a few tens of feet occurred on the fault, and as in the case of the other fault described, the later movement was in the opposite direction from the earlier movement.

DEFORMATION LATER THAN EARLY CRETACEOUS DEPOSITION AND EARLIER THAN TERTIARY DEPOSITION

In the Walnut Wells quadrangle, as elsewhere in the region, the orogeny that deformed Cretaceous and earlier rocks before the deposition of Tertiary rocks was the strongest period of deformation that had affected the area since Precambrian time. In the Big Hatchet Mountains and in other nearby ranges thrusting, overthrusting, strong folding, and high angle faulting took place. In the Walnut Wells quadrangle evidence of only strong folding and high angle faulting is exposed. Here the Cowboy Spring Formation and underlying formations were deformed but the overlying Timberlake Fanglomerate and other Tertiary formations were not disturbed by this orogeny. The dating of this deformation within close limits is not possible because the exact ages of these bounding formations are not known. The Cowboy Spring Formation is either latest Early Cretaceous or earliest Late Cretaceous in age. The Timberlake Fanglomerate and the immediately overlying extrusive rocks are of Tertiary age, but their ages within the Tertiary period are not known.

Growth of the Winkler anticline began prior to deposition of the Cretaceous section, and the anticlinal area must have been relatively high during deposition of the lower part of the Cretaceous section. This is indicated by the thinness of the pre-Mojado Crustaceous section in the area of the anticline as compared with its great thickness in nearby areas. Near the anticline the Hell-to-Finish Formation and the U-Bar Formation are thin. The pre-Mojado Cretaceous section near the anticline is about 2500 feet thick, whereas the corresponding section in the Big Hatchet Mountains is about 4400 feet thick. Though the thinness of these beds may be due to deposition on a remnant topographic high, it may be due partly to continued rising of the anticline during deposition.

During deposition of the Mojado Formation, the anticline was not active and the anticlinal area was not topographically high. This is indicated by the apparently normal thickness of the Mojado and the lack of coarse conglomerate. However, by the end of Mojado time the anticline was again active, and cobbles eroded from the rising anticline contributed to deposition of the Cowboy Spring Formation.

Evidence indicating that there was growth of the Winkler anticline after deposition of the Cretaceous section and before deposition of the Tertiary section is seen in the ages of the rocks that underlie the unconformity at the base of the Tertiary section. The erosion that preceded Tertiary deposition cut about 5000 feet more deeply into the stratigraphic section near Winkler anticline, where most of the Mojado Formation is gone, than it did to the south, where it cut only into the Cowboy Spring Formation. This pattern of erosion shows that the anticline continued to grow during this time and probably was elevated an additional 5000 feet; erosion prior to Tertiary deposition removed the 5000 feet of section.

A northeast-striking high-angle fault between U-Bar and Mojado beds is exposed near the head of Bennett Creek. As this fault is not found in the overlapping Tertiary rocks, it must have developed during this pre-Tertiary period of deformation. As is indicated on geologic section AA', Plate 2, this fault had a major throw; the U-Bar Formation is faulted against beds that are far above the base of the Mojado Formation. This fault probably extends eastward to the area of Mojado exposures where estimates of the thickness of the Mojado Formation were made. The fault would cause duplication of section and apparent thickening of the formation.

The upper part of the U-Bar Formation is exposed south of the Young Ranch where it is tightly folded. The occurrence of this formation so far south of its exposures on the southern flank of the Winkler anticline is anomalous. Also anomalous is the northwestern trend of the tight folds (axial planes strike northwest and dip northeast; axes plunge southeast) which is in sharp contrast to the northeast trend of the Winkler anticline. Only one mile west of the tightly folded area, exposures of Mojado Formation on the southern limb of the Winkler anticline strike northeast. Because the area between the tight folds and the southern limb of the Winkler anticline is covered with Tertiary rocks and alluvium, any pre-Tertiary structure separating the areas is concealed. To explain the observed relationships, a concealed fault is postulated that separates this tightly folded area from the Winkler anticline; the strike of this fault must lie in the northwest quadrant (pl. 1 and geologic section BB', pl. 2) in order to fit the map relationships. As the fault places the U-Bar Formation against high Mojado beds, the stratigraphic throw is large. This fault may have considerable bearing on the ore potential of the Red Hill mine (pp. 86-88). Because the fault does not cut the overlying Tertiary rocks, it must be assigned to this pre-Tertiary period of deformation.

The depositional record of the basal Tertiary Timberlake Fanglomerate may support the presence of the postulated fault. The immense size of boulders in the Timberlake Fanglomerate east of Cowboy Spring indicates a nearby source from a sharp topographic high. These boulders, some the size of houses, were derived from the nearby Cowboy Spring Formation. It seems probable that the boulders were eroded from the scarp of the highly elevated eastern block of the pre-Tertiary fault. This fault may lie less than a mile from the area of great boulders. Deposits of Timberlake Fanglomerate that extend for several miles north and south of the Cowboy Spring area, and the coarse limestone conglomerate in the lower Oak Creek Tuff northwest of the Red Hill mine, may have been derived from a high remnant ridge eroded from the elevated eastern block of the fault.

The system of northeast-striking high-angle faults that cuts Cretaceous and Permian rocks of Winkler anticline had its major development during the time between Cretaceous and Tertiary deposition. One of the faults extends beneath unfaulted Tertiary rocks near the head of Gillespie Creek. In a few instances, faults of this system had minor early movement prior to Cretaceous deposition (p. 69). Weak rejuvenation of some faults, apparently during or after Tertiary deposition, produced fractures which were filled with silica and rarely with ore minerals.

DEFORMATION DURING TERTIARY DEPOSITION

In the southern part of the Animas Mountains, mild deformation proceeded during deposition of the Tertiary rocks. Evidence of deformation is seen in the emplacement of the plutonic rocks of the Animas stock and the Walnut Wells plug, which previously have been described. Further evidence is seen in angular unconformities within the Tertiary section and in the boulder conglomerates composed of pre-Tertiary detritus that are interbedded with Tertiary extrusive rocks. The occurrence of these unconformities and conglomerates at several specific levels of the Tertiary sequence suggests that deformation was only periodically active. However, deformation could have been continuous. The fact that its effects are reflected only at certain horizons may be due to relatively rapid deposition of parts of the Tertiary section during which times the effects of deformation were so slight as to leave no discernible record. Such periods could have been followed by relatively long periods of nondeposition and erosion during which the cumulative effects of mild deformation were sufficient to leave their traces on the section. In any case, the period of Tertiary deposition in the area was one of crustal unrest.

Deformation was relatively weak and its effects may be noted only through careful observation.

Several miles west of the quadrangle, near the head of Indian Creek, a bed of limestone boulder conglomerate is interbedded with the pre-Gillespie extrusive rocks. Also, northwest of the Red Hill mine, chiefly in sec. 24, T. 30 S., R. 18 W., a thin bed of limestone cobble and boulder conglomerate with some boulders up to 100 feet in length is found in the Oak Creek Tuff (p. 33). The detritus was derived principally from the Epitaph Dolomite and Concha Limestone. These occurrences indicate high relief during deposition of the lower formations of Tertiary age because the boulders had to come from nearby limestone mountains. Such high relief after the beginning of deposition of Tertiary extrusive formations, of course, may have been caused by pre-Tertiary elevation and erosional dissection. However, the high relief may have been caused by the elevation of mountains during early Tertiary faulting.

In the southwestern part of the quadrangle Deer Creek follows a rather straight course. Along Deer Creek certain abrupt changes in the characteristics of the formations occur that indicate structural complications. For these reasons this linear zone is called the Deer Creek lineament (fig. 11). The lineament has a direction of about N. 5° W., and it may be traced for about 5 miles.

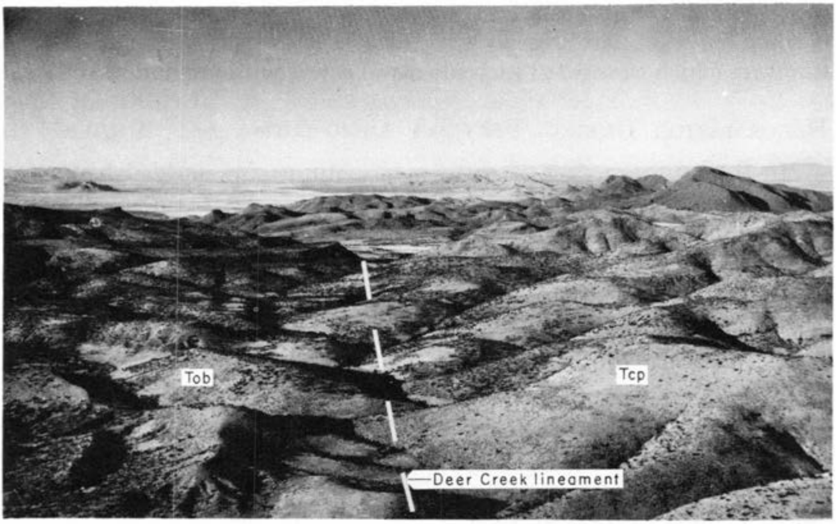


Figure 11

VIEW IN ANIMAS MOUNTAINS LOOKING NORTH ALONG DEER CREEK LINEAMENT

Gillespie Mountain is in right background; Animas Valley is in left background. (Photo by Zeller)

The abrupt changes that occur in the formations along the lineament are the following:

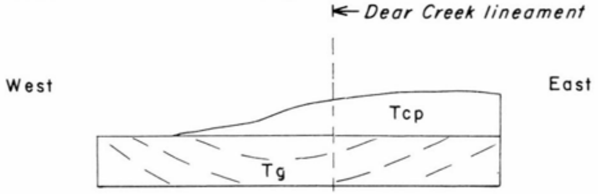
1. The Center Peak Latite is present and thick to the east and is absent to the west of the lineament.
2. The Park Tuff is present west of the lineament, is absent east of the lineament (except in a few places where it rests upon Center Peak Latite a few hundred yards east of the lineament), and is seen to wedge out along the lineament south of Frankie Tank.
3. East of the lineament, fanglomerate that is thought to correspond to the OK Bar Conglomerate consists entirely of Center Peak Latite detritus. A short distance west of the lineament more than 50 feet of the basal OK Bar conglomerate contains some detritus derived from the Center Peak Latite. But, the overlying several hundred feet of OK Bar Conglomerate has no Center Peak Latite detritus and is composed almost entirely of detritus derived from the Pine Canyon Formation to the northwest.

It would seem possible to explain the Deer Creek lineament as a fault along which the east and west blocks moved in opposite directions at different stages during deposition and erosion. Should such a fault exist, it would be visible on the steep canyon wall at the head of Double Adobe Creek near the middle of the eastern boundary of sec. 1, T. 32 S., R. 19 W. Here there is no evidence of such a fault. Instead, two surfaces of unconformity intersect along the lineament.

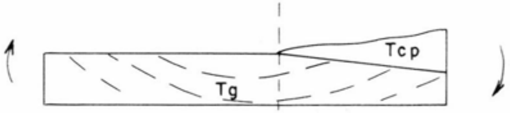
A hypothesis that would explain the origin of the lineament must explain the reason why Deer Creek follows the lineament, must explain the abrupt changes in the characteristics of the formations along the lineament, and must take into consideration the significance of the intersecting unconformities. The hypothesis outlined below and illustrated in Figure 12 satisfies these conditions (see also geologic sections CC' and DD', pl. 2).

Sketch A of Figure 12 shows the deposition of the Center Peak Latite on the erosion surface cut into gently deformed Gillespie Tuff. At the head of Double Adobe Creek planar flow structures in the Gillespie Tuff are beveled by the erosion surface. Evidence from the area west of the quadrangle indicates that the Gillespie is folded in a broad syncline which has been cut by the erosion surface (see geologic map of southern Animas Mountains, Zeller, 1962). As indicated on the sketch, the Center Peak Latite thickens east of the lineament.

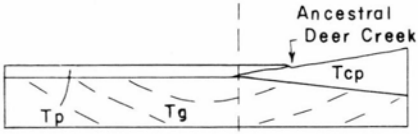
Sketch B shows the area being tilted eastward and eroded, an occurrence that produces two intersecting unconformities. This erosion accounts for the absence of the Center Peak Latite west of the lineament. The absence of the latite west of the lineament cannot be explained by assuming that the termination of the latite was the western end of the



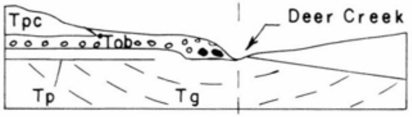
A. Deposition of Center Peak Latite on erosion surface cut on deformed Gillespie Tuff.



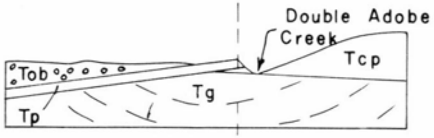
B. Area tilted eastward and eroded. Center Peak Latite removed from west of lineament. Area east of lineament remains higher.



C. Deposition of Park Tuff. Ancestral Deer Creek migrates down slope upon resistant Center Peak Latite.



D. Deposition of OK Bar Conglomerate. Erosion results in location of present course of Deer Creek between conglomerate surface and Center Peak Latite (Frankie Tank area)



E. Sketch of relationships at head of Double Adobe Creek showing intersecting unconformities. Dips exaggerated.

EXPLANATION

Tpc	Pine Canyon Formation
Tob	OK Bar Conglomerate
Tp	Park Tuff
Tcp	Center Peak Latite
Tg	Gillespie Tuff

Figure 12

SERIES OF SKETCHES SHOWING EVOLUTION OF DEER CREEK LINEAMENT flow, because a short distance east of the lineament the formation is too thick to have reached its limit so abruptly, and the line along which the latite disappears is too straight.

The area east of the lineament probably remained somewhat higher because the Center Peak Latite is more resistant to erosion than the Gillespie Tuff. This condition is necessary in order to explain the distribution of the Park Tuff as shown in sketch C.

In sketch C the Park Tuff with its lower member of sandstone is deposited. If this formation is projected from its present exposures eastward across the lineament it would butt againt the Center Peak Latite. For this reason the latite must have been higher and must have formed the eastern limit of Park Tuff deposition. The constant thickness of the Park Tuff west of the lineament indicates that the latite formed a residual high on the pre-Park Tuff erosion surface, and that the surface was not tilted westward to cause elevation of the latite.

Ancestral Deer Creek was probably in existence by this time, and its channel probably migrated down the slope of the resistant Center Peak Latite and removed the portion of soft Park Tuff that originally lay east of the lineament. South of Frankie Tank along the lineament the Park Tuff was evidently removed by ancestral Deer Creek and the OK Bar Conglomerate rests directly upon the Gillespie Tuff (sketch D).

Sketch D shows the deposition of the OK Bar Conglomerate and the location of the present course of Deer Creek between the sloping conglomerate surface and the Center Peak Latite.

Early deposition of the OK Bar Conglomerate formed a uniform bed west of the lineament. The basal beds near the lineament contained detritus from the Center Peak Latite, which is shown in the diagram as black dots. This deposition was followed by extrusion of the thick sequence of Pine Canyon flows to the northwest, which formed the dominant high of the area at that time. After extrusion of the Pine Canyon flows, OK Bar Conglomerate deposition continued, and nearly all the detritus was derived from the flows. The heavy supply of detritus from the west and northwest built a fan deposit of conglomerate that sloped eastward and tended to force the channel of Deer Creek eastward against the contact with the resistant Center Peak Latite.

In summary, the basic cause of the lineament was the eastward tilting of the area that occurred after deposition of Center Peak Latite; the tilting resulted in removal of the latite to the west of the lineament and preservation of a high area of latite to the east. Deer Creek follows the lineament because its course was forced eastward against the resistant latite mass by the build-up of thick OK Bar Conglomerate to the west.

Prior to the present study, no apparent correlation between pre-Tertiary and Tertiary structure in southwestern New Mexico had been proven. However, the Winkler anticline, which started its growth between Leonard and Trinity time and continued its growth during and after Cretaceous deposition, continued to grow during Tertiary time. This growth is shown by the diastrophic attitudes of the volcanic rocks surrounding the core of the anticline. In general, these rocks dip away from the core zone (geologic section AA', p1. 2). Tertiary growth of the anticline is also indicated by the fact that some of the Tertiary formations thin and disappear in the area of the anticline.

Alper studied high-angle faults along the borders of the Animas stock, which were probably formed with the emplacement of the stock. The stock was probably a crystal mush when intruded (p. 41), and it partially made room for itself by faulting its roof. Elston (1957) has described similar faulting associated with other intrusive activity in New Mexico, and this type of faulting is found on top of salt domes (Parker and McDowell, 1951; DeGolyer, 1925).

Immediately southwest of the Walnut Wells quadrangle, basalt or andesite flows and pyroclastic beds rest with sharp angular unconformity upon OK Bar Conglomerate and older Tertiary formations (see reconnaissance geologic map of southern Animas Mountains, Zeller, 1962). In some cases these flows lie along the top of the high western ridge of the Animas range, having been elevated to this position by the latest period of faulting. Dikes of similar composition southwest of the quadrangle occupy the channels that supplied the extrusives, and the olivine andesite lenticular intrusion of this quadrangle (p. 61) probably belongs to this same phase of igneous activity. Basic flows of identical characteristics rest with angular unconformity upon the older Tertiary section in the Alamo Hueco Mountains (see reconnaissance geologic map of Dog Mountains quadrangle, Zeller, 1958, where the formation is mapped as "Ta—late Tertiary andesite flows"). In that area and also southwest of the Walnut Wells quadrangle, the flows truncate earlier Tertiary faults. Thus, between deposition of the earlier Tertiary section and the late basic flows, folding and erosion occurred to form the angular unconformity, and faults were formed.

DEFORMATION AFTER TERTIARY DEPOSITION

The entire Tertiary section was involved in the last period of deformation that affected the area, and this deformation has been active into Recent time. This activity may have been a continuation of Tertiary deformation with increased intensity. Structures that have not involved the latest Tertiary deposits cannot be proven to belong to this last period of deformation. Folds and faults of a number of different types were formed during this disturbance.

The folds, which cover large areas, are gentle and have dips that seldom exceed 10 degrees. Their axes trend north-south and have a slight plunge southward.

A variety of fault types cut the Tertiary rocks. In the northwestern part of the quadrangle the dominant structures are northwest-trending high-angle faults. In the southwestern part of the area there are a number of east-west trending high-angle faults, some of which have moderately large displacements. This east-west trend appears to be dominant west and southwest of the quadrangle in the Animas Mountains (Zeller, 1962), and a similar fault pattern was mapped by Zeller (Dane and Bachman, 1961) in the Tertiary rocks of the southern Peloncillo Mountains.

A peculiar checkerboard-like fault pattern is found in the extreme southwestern corner of the quadrangle and in the area to the west and southwest in the adjoining quadrangles. Individual blocks are bounded by high angle faults and each block moved upward or downward with respect to neighboring blocks. The fault that lies about 1/4 mile south of Spring Canyon belongs to this system. The sinuous pattern of the fault shown on the map suggests a low angle thrust fault, but careful work has shown it to be a high angle fault that has irregularities that may be likened to gigantic mullion structure.

Along the northwestern part of the range a series of normal faults of the Basin and Range type forms the boundary between the bedrock of the mountain block and the alluvium of the valley. In the places where the faults are shown on the geologic map (pl. 1) as passing through alluvium, a fault scarplet is found, which indicates that the latest movements of the faults have been recent and that the faults may still be active. The exposed faults represent a few of perhaps a number of closely spaced sub-parallel normal faults that flank the west side of the Animas Mountains.

A similar system of normal faults is found on the east side of the Animas Mountains. Northeast of the Timberlake Ranch a series of relatively small normal faults are found (geologic section CC', pl. 2). A system of normal faults may lie buried beneath valley fill several miles east of the mountains (p. 64).

Mineral Deposits

MANGANESE DEPOSITS

LOCATION

Manganese mineralization occurs in the northwestern part of the Walnut Wells quadrangle in secs. 31, 32, and 33, T. 29 S., R. 18 W., and in secs. 5 and 6, T. 30 S., R. 18 W. The chief deposit and the only recently active mine is that of the Combined Minerals Corporation.

DESCRIPTIVE GEOLOGY

The chief manganese deposits occur in the lower portion of the Oak Creek Tuff as fissure veins and breccia fillings along normal faults. The faults vary in strike from N. 14° E. to N. 21° W. and generally dip 80° to 85° to the west, though some dip 85° to 89° to the east. The throws along the faults are probably less than a few hundred feet since the faults have not brought different formations in contact with one another.

Most of the weak mineralization in the tuff appears to have filled small fissures and breccias associated with faults of very small displacement. All these minor faults follow the same general pattern as major faults a few miles south of the Combined Minerals Corporation manganese mine. Brecciation and slickensiding of ores indicate that there were recurrent movements along these faults.

A few small manganese deposits occur in north-trending fractures in the Animas stock.

The most important ore mineral is psilomelane, which occurs throughout the mineralized area. The mineral has been tentatively identified from polished sections on the basis of physical and optical properties, and etching reactions described by Short (1940, p. 162). The mineral shows four extinctions per revolution with polarized light. The mineral is hydrous, and chemical and flame tests (Ford, 1932, p. 370) show it contains barium; the presence of barium in a hydrous manganese oxide is indicative of psilomelane (Fleischer and Richmond, 1943).

The mineral commonly occurs in massive, botryoidal, or reniform layers or as coatings on fragments of quartz latite tuff. Coatings commonly are less than 1/4-inch thick but may be as much as 6 inches thick. A minor amount of iron oxide is intermixed with the manganese ore. According to Mr. Bishop, mine foreman, ore concentrates of 40 to 45 percent manganese produced at the Combined Minerals mine contain about 8 percent silica, less than 6 percent iron, and about 0.25 percent combined lead, copper, and zinc.

Black calcite is present but is much more limited in distribution and abundance than the psilomelane ores. Three hundred yards north of the shaft of the Combined Minerals mine the vein is chiefly composed of black calcite. It coats and cuts the psilomelane and is therefore younger than the psilomelane.

Fine- to medium-grained white calcite is commonly present as thin layers cementing brecciated psilomelane and black calcite, and as veinlets cutting masses of psilomelane and black calcite. Psilomelane was not observed to surround or to cut calcite anywhere in the entire mineralized area. Polished and thin sections also show that the calcite cuts and fills open spaces in the psilomelane. Therefore the white calcite also is younger than the psilomelane. A minor amount of light pink calcite, which shows the same relations to the psilomelane as the white calcite, is also present.

Finely crystalline milky quartz occurs in the manganese deposits, though not nearly so commonly as the white calcite. The quartz fills open spaces in the psilomelane ores. In some localities the quartz is younger than the calcite, though the two minerals may have had overlapping periods of deposition.

Light green fluorite and some barite occur in the vicinity of the Combined Minerals mine. The fluorite is generally located away from the ore shoot in the hanging wall. The relationship of the fluorite and barite to the ore minerals is not clear.

No replacement of country rock by manganese oxides was observed in the field; polished and thin sections demonstrate that neither the matrix nor the coarse crystals of the tuff were replaced. Studies of thin sections showed no alteration of the tuff near manganese oxide veinlets.

ORIGIN

The manganese ores of the Walnut Wells quadrangle are thought to have been directly deposited as manganese oxides by shallow hydrothermal solutions of low temperature which probably were associated with the igneous activity.

Although psilomelane is generally regarded as a supergene mineral (Palache, Berman and Frondel, 1944, p. 669) and often occurs as a secondary mineral (Lasky and Wootton, 1933; Harder 1910, 1916; Lindgren, 1933), here there are indications that the psilomelane deposits are hypogene and are not the result of oxidation of primary manganese carbonates or silicates.

Psilomelane is the earliest deposited manganese mineral now present. There is no evidence of leached, weathered, or altered manganese-bearing minerals from which the psilomelane could have been derived, nor are there any boxworks or cavities in which primary minerals could have occurred. Furthermore, it is difficult to picture erosion sufficiently uniform and rapid to remove all evidence of a leached or oxidized zone over the large area in which the psilomelane deposits are found.

Many other manganese deposits in New Mexico, occurring in brecciated volcanic rocks, are considered to have been deposited as primary oxides from hydrothermal solutions (Jicha, 1956; Eugene Callaghan, oral communication, 1956). The manganese deposits of the Luis Lopez district, Socorro County, New Mexico (Miesch, 1956), are very similar to the deposits of the Walnut Wells quadrangle. There, psilomelane was deposited in brecciated rhyolite prior to the deposition of black calcite, quartz, and barite. Miesch believes that the psilomelane was deposited directly as oxides from cool thermal solutions associated with the late volcanism of the region.

In the Walnut Wells quadrangle psilomelane was noted only in the Oak Creek Tuff and the Animas Quartz Monzonite. Zeller found psilomelane southwest of these occurrences in the high saddle several hundred yards west of the summit of Animas Peak; here it fills fractures in a post-Gillespie welded tuff tentatively assigned to the Park Tuff.

The ore-bearing solutions in the Walnut Wells quadrangle were probably of a low-temperature and epithermal nature. The low temperatures of the solutions are indicated by the mineral assemblage, especially by the occurrence of light green fluorite (Grogan and Shrode, 1952), and by the lack of alteration and replacement of host rocks by ore solutions. Breccia- and fissure-filled deposits, especially in Tertiary extrusives, probably occurred at shallow depths, inasmuch as open-spaced breccias and fractures are not likely to have formed at greater depths.

Manganese oxides, barite, calcite, silica, and minor amounts of fluorite commonly have been or are being directly deposited by hot to warm springs which are located in volcanic areas. Commercial grade manganese oxides have been deposited directly by ancient springs (Callaghan and Thomas, 1939) and are presently being deposited by neutral to alkaline springs and geysers (Allen and Day, 1935; White, 1955). D. F. Hewett (1932, p. 563) reported finding manganese in amounts up to 117 ppm in spring waters, and he found that river waters in temperate zones commonly have a manganese concentration of 0.5 to 5 ppm.

The similarity of the mineral assemblage of the deposits mentioned in the above paragraph to that of the manganese ores of the Walnut Wells quadrangle and their common association with volcanic activity suggest that the manganese ores of the Walnut Wells quadrangle may have been deposited by solutions that were somewhat like present day manganese-bearing thermal springs.

The manganese deposits of the Walnut Wells quadrangle have the same general structure, mineralization pattern, and volcanic association as many other manganese deposits in the southwestern United States and northern Mexico (Wells, 1918; Trask and Cabo, 1948; Fleischer, Axelrod, and Neuschel, 1956; Miesch, 1956; Jimenez, 1956). Some of the similar deposits of Sonora and Chihuahua are located approximately

100 miles from this quadrangle (Trask and Cabo, 1948, p. 236, 273). In the Talamantes district of Chihuahua, Mexico, manganese oxides composed of psilomelane, cryptomelane, hollandite—cryptomelane, and coronadoite occur in brecciated rhyolite along faults (Wilson and Rocha, 1948, p. 183). The presence of tungsten oxide in the manganese oxides is considered to be an indication that the deposits are hypogene (ibid., p. 200).

COMBINED MINERALS CORPORATION MINE

The Combined Minerals Corporation mine in the SE1/4NE1/4 sec. 31, T. 29 S., R. 18 W. is located in the chief manganese deposit. The area was originally staked out into claims and worked in 1910, and some work was carried on during the First and Second World Wars. Monroe Dunagan, George Dunagan, Jr., and Jewel Birtrong relocated the claims in 1948 and leased them to Combined Minerals Corporation in 1954. According to Mr. Bishop, mine foreman of Combined Minerals Corporation, 150 tons of concentrates containing 40 to 45 percent manganese were produced in 1954-55 within a 5-month period. Originally the present company sent ore to the stockpile at Deming, New Mexico, but later ore was sent to the National Stockpile at Denver, Colorado.

A vertical shaft, about 70 feet deep, was sunk in brecciated tuff. From this shaft a drift 173 feet long was driven along the orebody. Mining was by open overhand stoping using stulls to support the walls and to provide working platforms.

A brecciated ore shoot 6 feet wide with some individual manganese oxide masses up to 6 inches thick was mined. Ore was stoped from the drift to within 25 feet of the ground surface. In the summer of 1955 six men worked the mine with one shift a day.

FUTURE EXPLORATION

Indications of ore, which have not been explored, may be seen in many areas along faults. Some ore was observed near the northern part of the main fault along Animas Valley. Future exploration for ore deposits might well be directed toward brecciated manganese-bearing areas in the Oak Creek Tuff that are indicated on the map (pl. 1), particularly in the W1/2 NE1/4 sec. 6, T. 30 S., R. 18 W.

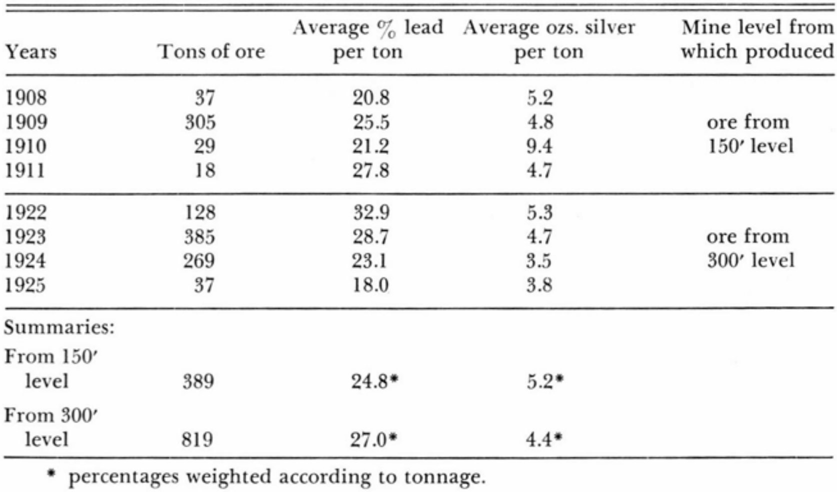
OTHER MINERAL DEPOSITS

RED HILL MINE

The Red Hill mine is located on the hill about 2 miles northeast of the mouth of Gillespie Creek canyon. Mr. J. F. Fitch of Hachita, New Mexico, made available some of the settlement sheets from the El Paso smelter on ore shipped from the mine between 1922 and 1925, and he also authorized the publication of maps of the two working levels of the mine. Mr. Carl F. Schaber of Deming, New Mexico, made available a report on the geology of the Red Hill mine by John Wellington Finch and a partial list of ore shipments to the El Paso smelter from 1908 through 1924, and he authorized the publication of this information.

The Red Hill mine produced lead and silver ore during various periods of operation for many years. It is not known when the mine was first opened nor when shipments of ore started. The shipments summarized in Table 15 represent only a fraction of the total ore sent to the El Paso smelter, and it is known that some ore was shipped to the Douglas smelter.

TABLE 15. PARTIAL PRODUCTION FROM RED HILL MINE.



Years	Tons of ore	Average % lead per ton	Average ozs. silver per ton	Mine level from which produced
1908	37	20.8	5.2	
1909	305	25.5	4.8	ore from
1910	29	21.2	9.4	150′ level
1911	18	27.8	4.7	
1922	128	32.9	5.3	
1923	385	28.7	4.7	ore from
1924	269	23.1	3.5	300′ level
1925	37	18.0	3.8	
Summaries:				
From 150′ level	389	24.8*	5.2*	
From 300′ level	819	27.0*	4.4*	

* percentages weighted according to tonnage.

Assuming that the values of ore shown in Table 15 represent fair averages, it can be seen that the content of lead increases and the content of silver decreases at the deeper level. Several of the later smelter settlement sheets show 8.7 percent zinc and one shows 1.9 percent arsenic, antimony, and bismuth.

Most of the dumps have been shipped, and at present very little ore is found on them. Alper recognized small amounts of galena, cerussite, wulfenite, and pyromorphite.

The ore deposit of the Red Hill mine is essentially a breccia and fissure filling in Oak Creek Tuff. Galena, quartz, and calcite have been deposited in the tuff along zones ten feet wide in three small normal faults of slight displacement. The faults strike N. 45° W. and dip 75°-85° NE. The country rock shows only minor replacement but has been moderately bleached and silicified and stained by iron oxides, manganese oxides, chrysocolla, and malachite. The ores may have originated from solutions associated with the same igneous phase during which the Animas stock was emplaced.

A geologic report, dated December 1, 1926, written by John Wellington Finch on the Red Hill mine includes much basic information. Excerpts from the report are quoted as follows:

> . . . The Red Hill veins outcrop across the summit of a small isolated rhyolite hill for a distance of over 2000'. The main vein strikes northwest-southeast and dips . . . to the northeast. At a point near the working shaft a smaller vein branches from the hanging wall side of the main one and strikes northwest more or less parallel with it. The branch vein has a flatter dip (65^{0}) to the northeast. In the region of junction of the minor vein with the main vein a high grade ore body extends for about 200' along the strike at the outcrop and was extracted from a gloryhole and down to a depth of 100' by former operators. Ore continued to be found downward below the open cut in both the main vein and in the branch vein, although the more important bodies have been found in the former. Both veins are typical fissure veins of unusual regularity of strike and dip.
>
> Production from the mine has come entirely from the oxidized zone. The ore is lead, contains only a moderate amount of silver, and is unusually free of other metals. In the oxidized zone the lead mineral is chiefly carbonate (cerussite) in many places surrounding a central core of the galena from which the carbonate has been derived. Also, coating such remnants of galena there are concentric layers of lead sulphate (anglesite), which represents an intermediate step in the alteration of galena to cerussite. In vugs and seams a still later mineral lead molybdate (wulfenite), a somewhat rare mineral, coats the cerussite.
>
> The Western Exploration & Mining Company has deepened a winze which had been started below the 300 level, sinking it some 15' below water level in order to determine the nature of the sulphide ores. This work disclosed merely an increasing amount of pure galena but still considerably altered to anglesite and cerussite, but no apparent zinc or other metallic minerals, which are sometimes found in the sulphide zone below outcrops of lead carbonate, were discovered. It appears to be fairly well assured that the vein will continue downward as a distinctly lead vein.
>
> . . . The Red Hill vein is strictly a quartz vein. The ore now exposed in the mine was in its original form galena and quartz deposited deep in the earth. The quartz in the oxidized zone along the middle of the vein is honeycombed and full of cavities from which the galena has been dissolved and redeposited as cerussite, but it is more massive along the walls of the vein where it contained less galena.
>
> Since the main period of sulphide ore deposition the vein has been reopened repeatedly by movements along it and heavy gouges have been formed on its walls and within the ore. Such subsequent movements have doubtless aggregated a considerable amount of displacement. . . . The fault movements have broken the ore into blocks and in places into small fragments. Some of the latter have been rolled and rounded; also fragments of ore have been dragged considerable distances along the vein from the main ore shoots.
>
> . . . the rhyolite showing in the present mine workings . . . is underlaid by limestone of a character which should be amenable to replacement by galena. There are cases in which replacement of a limestone by lead ores from a fissure passing through it has not taken place, generally on account of the unfavorable nature of the limestone or because of the damming off

> of the solutions passing along the vein by clay gouges on its walls so that they did not escape and spread into the limestone. In this case there is sufficient evidence in the mine that the gouges showing along the vein were formed subsequently to the principal period of ore deposition and there is a good chance therefore that there was probably nothing in the structure of the vein fissure to hinder ore minerals from spreading into the limestone which is of the same age and to all appearances similar in character to the blue limestone of Leadville and should have been favorable to replacement.•
>
> . . . It is somewhat unexpected to find such rich lead ores in the rhyolite as the mine contains. Rhyolite is not generally favorable to such mineralization. The occurrence suggests that unusually effective ore solutions circulated in the vein.

Finch continued by showing that the base of the Tertiary volcanic section was expected to be about 500 feet below the collar of the shaft, and that limestone should be found under the volcanic rocks. He emphasized the possibility of replacement ore bodies in the limestone and he concluded the report as follows: "The work, now begun, of sinking the Red Hill shaft into the limestone horizon and exploring the vein therein is a speculative development which may open up important ore shoots of the Leadville type."

Since the writing of Finch's report, the shaft (vertical, with one compartment and manway) was sunk to the 400 foot level and was bottomed in volcanics. Maps of the two working levels of the mine, the 150-foot and the 300-foot levels, are shown in Figure 13. According to Carl F. Schaber, the mine is in good condition to a depth below the 150-foot level where the shaft has a bulkhead. The water table apparently lies between the 150- and 300-foot levels.

A study of the geology in the area near the mine indicates that the mine is in the lower part of the Oak Creek Tuff, which in this area rests directly upon pre-Tertiary rocks. The location of the mine in the lower part of the Oak Creek Tuff is indicated by the proximity of the mine to the basal contact near the Winkler Ranch, and by the presence of a limestone conglomerate bed interbedded with the tuff about 11A miles north and northwest of the mine (p. 33). Near Winkler Ranch the Oak Creek Tuff rests upon the Mojado Formation; these formations are locally separated by thin remnants of Timberlake Fanglomerate.

It is not known which sedimentary formation immediately underlies the Oak Creek Tuff at the Red Hill mine. The nearest exposed pre-Tertiary rock is the sandstone of the Mojado Formation near the Winkler Ranch, and if there are no structural complications between the ranch and the mine, the Tertiary rocks at the mine are probably underlain by the Mojado. However, a fault concealed by Tertiary volcanic rocks is probably present west of the Young Ranch (pp. 72-73). The area near the Young Ranch where the U-Bar Formation is ex-

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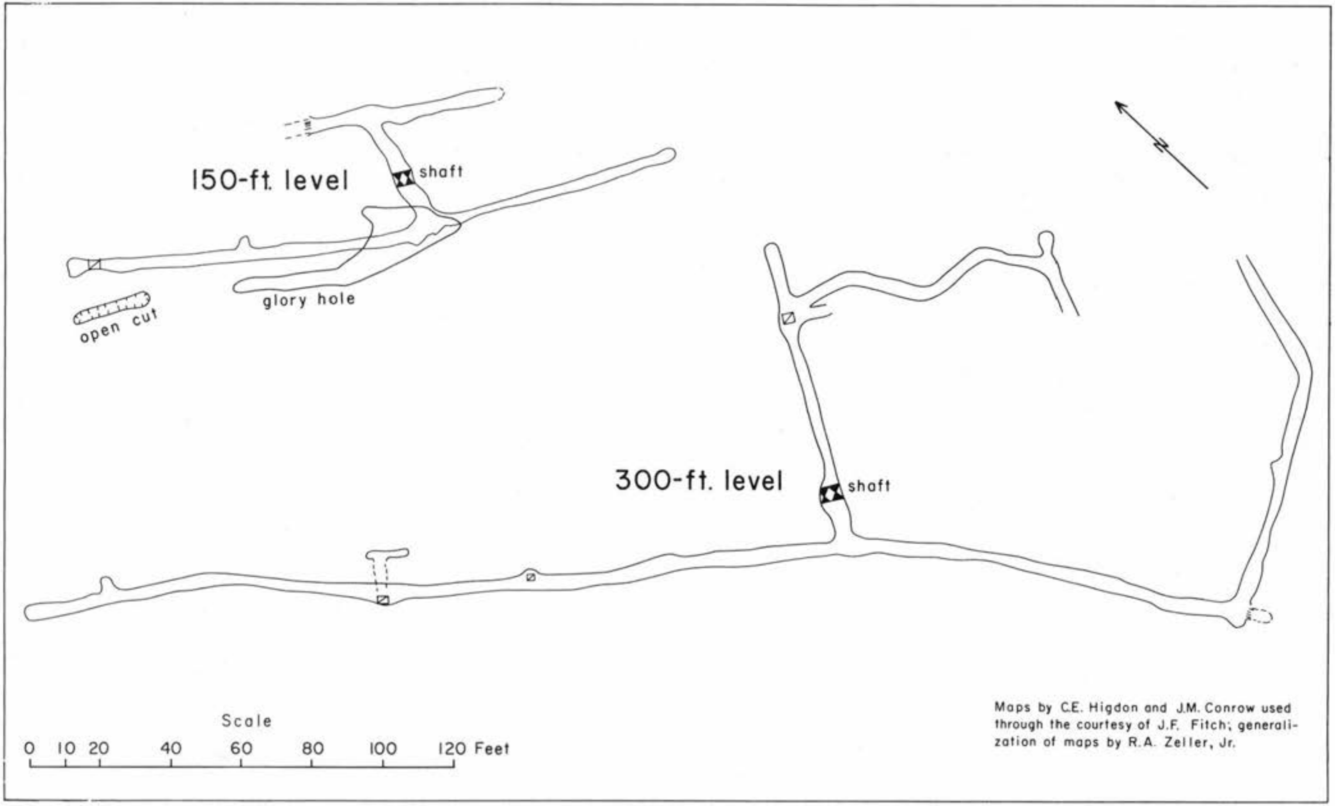
• The limestone possibly present below the volcanic rocks is Cretaceous and is not the same age as the Leadville Limestone.



Maps by C.E. Higdon and J.M. Conrow used through the courtesy of J.F. Fitch; generalization of maps by R.A. Zeller, Jr.

Figure 13
MAPS OF 150-FOOT AND 300-FOOT LEVELS OF RED HILL MINE

posed was apparently elevated by several thousand feet. If this fault passes between Winkler Ranch and the Red Hill mine, pre-Tertiary rocks near the mine may have been elevated enough so that erosion prior to Tertiary deposition exposed limestone of the U-Bar Formation or of earlier formations. Thus, either the Mojado Formation or limestone of Cretaceous or earlier age underlies the Oak Creek Tuff at the mine.

In the Hornet and American mines in the Little Hatchet Mountains, replacement bodies of ore are found in Cretaceous limestone similar to that of the U-Bar Formation. In view of the strength of the mineralization in the tuff at the Red Hill mine, similar replacement ore bodies may be present in any such underlying limestone. Detailed mapping of the area between the Red Hill mine and the Winkler Ranch may yield information upon which an estimate of the depth to the pre-Tertiary rocks could be based.

GILLESPIE MINE

The Gillespie Mine is located in sec. 4, T. 31 S., R. 18 W., near the axis of the Winkler anticline. This mine and smaller mines nearby were located during the winter of 1880-1881 and were worked for silver found in cerargyrite at shallow depths. Silver prospecting was intense for a time as is shown by the great number of shallow workings and by the number of mining claims filed in the courthouse. To help regulate the activity the miners organized the area into the Gillespie Mining District. The boom town of Gillespie or Gillespieville flourished briefly, but it was abandoned when the miners, discouraged by no further ore discoveries, moved on to more promising areas. Since the early 1880's the Gillespie mine and nearby mines have not been worked.

The Gillespie mine was developed along a silicified vein which *strikes N. 72° W. and dips 60° NE. Massive silica-rock occupies the vein and forms a prominent rib on the hill slope. The mine lies in calcareous siltstone of the Earp Formation within 50 feet of the Earp-Colina contact. Because the contact dips away from the mine, the Colina Limestone was not penetrated underground. Two shafts reported to be 85 feet and 100 feet deep were sunk on the vein. However, as the workings are at present dangerous, they were not entered.

Cerargyrite, the ore mineral mined, was not noted on the dump. The chief gangue minerals are calcite, siderite, and quartz; malachite and azurite also are present in small amounts on the dump. Numerous silicified fractures in the Winkler anticline, particularly in the limestone formations, have similar mineral assemblages, and most are subparallel in strike.

Concerning the origin of the ore, Alper suggests that similarities in nature of ore and trend of fracturing between the Gillespie mine and the Red Hill mine areas indicate that **the hydrothermal solutions which** emplaced both ore bodies may have originated during the same magmatic phase. Spatial relations further indicate that mineralization in the limestones in the Gillespie mine area may have been associated with the monzonite of the Walnut Wells plug, whereas mineralization in the Red Hill mine area may have been associated with the Animas stock.

FLUORITE PROSPECTS

Two areas of massive Horquilla Limestone along the axis of the Winkler anticline near the center and north of the center of sec. 3, T. 31 S., R. 18 W. were almost completely replaced with novaculite-like chert. The rock is crisscrossed with innumerable fractures, which may be associated with late folding of the anticline; most of the fractures are filled with crystalline quartz. However, upon the walls of some fractures fluorite was deposited, and the centers of the veins were filled with crystalline quartz. Fracture fillings of fluorite range up to 3 feet wide, and float of fluorite is common on parts of the outcrops. At the surface the fluorite apparently does not occur in veins of mineable length. Associated with the fluorite are rare crystals of very pale amethyst and yellow quartz (citrine). Several prospect pits recently have been dug on fluorite exposures.

SILICIFICATION

Volcanic rocks throughout the sequence have been moderately silicified along some faults. The limestones of the Winkler anticline have been intensely silicified in the axial area along fault planes, bedding surfaces, and fractures. Most of the silica replaced the limestone and some was deposited in open spaces in brecciated and silicified limestone. This silica is generally massive, cherty, and yellowish brown. Silicification was probably related to the various stages of Tertiary igneous activity, and was accompanied by ore mineralization in some places, as in the Gillespie mine and the fluorite prospects.

Appendix

STRATIGRAPHIC SECTIONS

GILLESPIE CREEK SECTION

The Gillespie Creek section, measured by Alper and subdivided into formations and gross lithologic units by Zeller, is on the eastern nose of Winkler anticline. The section starts in the N1/2 NE1/4 sec. 3, T. 31 S., R. 18 W. and continues through the SW1/2 SW1/4 sec. 35, T. 30 S., R. 18 W. From the Horquilla-Earp contact the section proceeds through 612 feet of Earp Formation, crosses the pre-Cretaceous unconformity, and traverses the Hell-to-Finish and U-Bar Formations. Description of the Gillespie Creek section is as follows:

		Thickness (feet)
Mojado Formation.		
U-Bar Formation:		
H.	Biohermal limestone unit: Limestone, medium-grained, bluish-gray, weathered pale blue, with chert zones, many beds rich in rudistids and others in *Orbitolina* sp., massive, lenticular, prominent cliff-former. Thickness ranges from 25 feet to 300 feet. Unit is biohermal.	
96.	Limestone beds in the following sequence: Limestone, medium-grained, gray, massive, rich in rudistids, 37 ft. thick; underlain by 10 ft. limestone bed rich in *Orbitolina* sp.; underlain by limestone rich in rudistids; underlain by cherty limestone; underlain by limestone, massive, rich in *Orbitolina* sp. and rudistids, 15 ft. thick	72
95.	Limestone, medium- to coarse-grained, gray and white, very thick-bedded; weathers pale blue; large oyster shells; some chert; calcite veinlets	52
94.	Limestone, same type as unit 93, contains red cherty zone	8
93.	Limestone, medium-grained, blue-gray, thick-bedded; weathers pale blue; rudistid zone, with oyster fragments	12
92.	*Orbitolina* zone, limestone, fine-grained, dark-blue, thick-bedded; weathers pale blue	16
91.	Limestone, medium-grained, gray, very thick-bedded; weathers pale blue; rudistids; more chert and calcite veinlets than below; cliff-former	52
90.	Limestone, medium-grained, dark-blue, very thick-bedded, beds tens of feet thick; weathers pale blue with numerous white and black patches of large oysters; minor amounts of small pieces of reddish-yellow chert; *Exogyra* sp. common, a few rudistids; cliff-former	40
89.	Limestone, coarse-grained, dark-blue, thin-bedded; weathers gray; scattered thin calcite veinlets	4
88.	Limestone, coarse-grained, grayish-blue, uniform color, thick-bedded; weathers pale blue; few oysters	12
87.	Limestone, coarse-grained, blue-gray, thin-bedded; weathers light blue, some sand; pelecypods	16

	Thickness (feet)
86. Sandy limestone, medium-grained, blue and cream, thin-bedded, friable, weathers buff; top is fossiliferous; pelecypods	16
Total unit H	300
G. *Orbitolina* limestone and sandstone unit:	
85. Limestone, fine-grained, dark-blue, thin-bedded; weathers pale blue, rich in *Orbitolina;* not resistant to erosion, forms low area; some brown sandstone, thin-bedded, fine-grained, argillaceous	304
F. Fossiliferous limestone, dolomitic limestone, and sandstone unit: Heterogeneous unit composed of interbedded coral limestone, blue-white to gray, massive; dolomitic limestone, dark-blue, weathered buff, finely crystalline, thin-bedded, rich in gastropods; limestone rich in oysters and other fossils; sandy limestone rich in oyster and other shells; and calcareous sandstone, yellow and gray, in 2- to 6-foot lenses.	
84. Coralliferous limestone, medium- to coarse-grained, blue-white, thick-bedded; blue, with numerous oblong and round white corals about 1 inch in diameter	26
83. Fossiliferous limestone, medium-grained, blue-gray, thick-bedded; weathers pale blue; tiny fossils	15
82. Limestone, medium-grained, gray, thick-bedded; large oyster fossils; *Exogyra* sp., and corals	10
81. Limestone, medium-grained, gray-brown with white dots, thick-bedded; rich in round small shell fragments; weathers speckled cream brown and light blue; pectens (?) 0.5 inch in diameter	20
80. Limestone, medium- to coarse-grained, blue with coarse patches of white coral, thick-bedded; weathers pale blue; rich in corals	16
79. Fossiliferous limestone, medium-grained, blue-gray with white specks, thin-bedded; brown chert; heterogeneous; weathers mottled brown and blue	8
78. Sandy limestone, medium-grained, blue and cream, thin-bedded; weathers rusty; friable	20
77. Limestone, fine-grained, dark-blue to gray; composed of nodules of limestone; weathers greenish cream; oyster shells, *Exogyra*, pectens; bed breaks up easily into nodules, forms low area	59
76. Sandy limestone, medium-grained, white and blue; oyster shells; lenses of dark, fine-grained limestone; weathers mottled greenish cream	5
75. Sandstone, fine-grained, yellow and gray; calcareous cement; weathers pink and cream; well indurated	2
74. Limestone, medium-grained, gray-blue; weathers grayish cream; sandy; oyster fragments; calcite veinlets	20
73. Sandstone, medium-grained, spotted white and gray, lenticular; calcareous cement; white specks are shell fragments; weathers grayish cream	6
72. Limestone, medium-grained, gray-blue; brownish-red chert gives weathered surface dirty rusty appearance; chert stands out in relief	8
71. Limestone, same type as unit 65	9
70. Limestone, same type as unit 65; very sandy	3
69. Limestone, medium-grained, gray-blue; weathers gray with cream overtones; in places sandy; numerous oyster fragments; chert; calcite veinlets; rough-weathered surface	16

	Thickness (feet)
68. Limestone, gray-blue; rich in oysters; heterogeneous appearance of surface due to fossils	8
67. Dolomitic limestone, fine-grained, dark-blue, thin-bedded; weathers buff	9
66. Sandy limestone, gray-blue; with oysters	3
65. Dolomitic limestone, fine-grained, dark-blue, thin-bedded; weathers buff; gastropods	19
64. Limestone, fine- to medium-grained, blue-gray; weathers blue with cream patches; oyster fragments	1
63. Sandy limestone, gray; sandy cream-colored weathered surface; scattered blue oyster fragments	2.5
62. Dolomitic limestone, fine-grained, dark-blue, thin-bedded; weathers buff; gastropods; horizon marker	9
61. Limestone, coarse-grained, brown-gray; consists almost entirely of oyster fragments; weathers rusty and cream gray; some rusty chert	1.5
60. Dolomitic limestone, fine-grained, dark-blue, thin-bedded; weathers buff; gastropods; important horizon marker	8
59. Limestone, fine- to medium-grained, mottled blue-gray and cream; some shell fragments	20
58. Limestone, medium-grained, gray to dark blue; thick-bedded; weathers light blue; small pelecypod fragments; thin calcite veinlets	9
Total unit F	333
E. Massive limestone unit:	
57. Limestone, medium-grained, dark-blue, thick-bedded; weathers pale blue; very pure, with only a few shell fragments; calcite stringers; locally large clusters of chert which weather brown; ridge-former	48
D. Sandstone and oyster-rich limestone unit: The upper 278 feet consists of sandstone, red, medium-grained, calcareous, thick-bedded; interbedded with lensatic beds of sandy and silty limestone and blue limestone. The limestone and many of the sandstone beds bear fossils. This arenaceous unit thickens southward.	
The remaining 479 feet consists mostly of limestone, blue, dense, medium- to coarse-grained, thick-bedded, lenticular, containing oysters; interbedded with numerous strata of oyster coquinite, blue, fine- to medium-grained, thin-bedded.	
56. Sandstone, medium-grained, cream-colored, thin-bedded, lenticular; weathers buff; grades into limestone	3
55. Limestone, fine- to medium-grained, blue; weathers pale blue to yellow; oysters	26
54. Sandstone, medium-grained, green-brown; sandstone, medium-grained, green-gray; small limestone lenses	10.5
53. Sandstone, medium-grained, white to cream	28
52. Sandstone, coarse-grained, green; black oyster shells	11
51. Limestone, medium-grained, blue; small pelecypods	12
50. Sandstone, medium-grained, red	12
49. Limestone, medium-grained, blue, dense; fossiliferous; pelecypods	2
48. Sandstone, medium-grained, red	9

		Thickness (feet)
47.	Sandstone, coarse-grained, green	2
46.	Sandstone, medium-grained, red	8
45.	Silty limestone, fine-grained, gray, lenticular; weathers cream brown	4
44.	Sandstone, medium-grained, green, lenticular; black metallic specks	3
43.	Sandstone, medium-grained, red	24
42.	Sandy limestone, medium-grained, blue; fossils	4.5
41.	Sandstone, medium-grained, red; calcareous cement	16
40.	Limestone, medium-grained, blue-gray	2
39.	Sandstone, medium-grained, red; calcareous cement	60
38.	Limestone, blue, fossiliferous, lenticular	5
37.	Sandstone, medium-grained, red; calcareous cement; weathers with maroon stains	31
36.	Sandstone, medium-grained, green-black; argillaceous matrix; blocky fracture	5
35.	Limestone, fine-grained, blue-black, dense; weathers cream blue; small round fossils; sporadic limonitic stains; in part weathered surface is mottled blue and gray	84
34.	Limestone, coarse-grained, brownish-gray; weathers light cream; thin calcite veinlets	24
33.	Dolomite, extremely fine-grained, grayish, dense; weathers creamy blue	3
32.	Limestone, fine-grained, gray-blue, thin-bedded; small pelecypod fossils; white coarse-grained calcite veinlets; isolated cream-colored fragments	24
31.	Limestone, coarse-grained, dark-blue, thick-bedded; weathers light blue; numerous brown pelecypods	4
30.	Coquina zone; large and small oysters, *Exogyra*, pectens; grades into gray dolomite, fine-grained; weathers cream	5
29.	Limestone, fine-grained, cream with dark-blue medium-grained patches; shell fragments; thin slivers of rusty-colored chert; weathered surface mottled and rough	6
28.	Limestone, fine-grained, blue-black, thin-bedded; beds few inches thick; rich in tiny round to oval fossils or concretions which weather dark-blue in contrast to light-blue weathered matrix; calcite veinlets	64
27.	Limestone, coarse-grained, blue, thick-bedded; black pelecypod fossils; transected by white to pinkish calcite veinlets, weathers to a rough surface with fossils having higher relief than limestone matrix	16
26.	Limestone, fine-grained, blue, thick-bedded, weathers pale blue; cherty blotches; calcite veinlets	12
25.	Limestone, fine-grained, blue, very fossiliferous with mainly pelecypods; brownish chert; weathers rusty	3
24.	Limestone, fine-grained, cream; oyster fragments	15
23.	Limestone, fine-grained, blue; white oysters; rusty chert; white calcite veinlets; some patchy pink stains 0.25 inch in diameter; weathers to form a rough irregular surface owing to differential erosion of chert and limestone	2
22.	Limestone, fine-grained, gray, thick-bedded; weathers buff; oysters; white calcite veinlets	28
21.	Limestone, fossiliferous with mainly oysters; weathers rusty	6

	Thickness (feet)
20. Limestone, coarse-grained, blue; weathers pale dusty blue; small yellow calcite veinlets; has oyster zones	78
19. Limestone, medium-grained, gray-blue, thin-bedded; weathers rusty; has brown chert and small fossils or concretions; also has pelecypod zones	47
18. Limestone, medium-grained, blue, thick-bedded; small fragments of pelecypods; near top a pink 5 inch limestone lens grades into pure blue limestone	31
17. Limestone, fine-grained, blue, thin-bedded; beds few inches thick; weathers buff; oyster and other pelecypod shells numerous. Upper 3 feet thick-bedded, weathers light blue, and has calcite veinlets	27
Total unit D	757
Total U-Bar Formation measured	1742
Conformable contact.	
Hell-to-Finish Formation:	
C. Green shale unit: Shale, dark-green, weathered light green to buff, brittle, thinly laminated; interbedded with limestone, blue, fine-grained, thin-bedded, rich in oysters; also interbedded with sandstone, cream-colored, medium-grained, calcareous, thin-bedded.	
16. Sandstone, medium-grained, yellowish tan; weathers cream, calcareous cement	6
15. Shale, fine-grained, dark-green, thin-bedded, beds less than 3 inches thick; weathers light green to buff; ironstone concretions; limestone lenses, fine-grained, dark-blue, about 3 feet thick, 4 feet long; rich in oysters	18
14. Sandstone, medium-grained, yellowish, thin-bedded	9
13. Shale, fine-grained, dark-green, thin-bedded; weathers light green; brittle; blocky fracture	15
12. Limestone, fine-grained, blue, thin-bedded	12
11. Shale, fine-grained, dark-green, thin-bedded; weathers light green to buff; highly brittle; blocky-fracture, with limonitic stains along fractures. Interbedded with limestone, blue, fine-grained, thin-bedded; and sandstone, cream, calcareous cement, beds 2½ inches. Partly concealed by wash	240
Total unit C	300
B. Interbedded limestone and sandstone unit: Upper half composed of sandstone, brown on fresh fracture, weathered red, medium-grained, thick-bedded and lenticular; and a bed of conglomerate composed of sandstone and a few limestone pebbles. Lower half consists of limestone, dark-blue, weathered light blue and cream, thin-bedded.	
10. Sandstone, medium-grained, tan, thick-bedded, lenticular; weathers red	15
9. Sandstone conglomerate, matrix medium grained, brown, thick-bedded, lenticular; weathers red, fossil wood; contains rounded limestone pebbles	5
8. Sandstone, medium-grained, brown, thick-bedded, lenticular; weathers red	20
7. Limestone, fine-grained, dark-blue, thin-bedded; weathers cream colored; lacks fossils	20

	Thickness (feet)
6. Limestone, fine-grained, dark-blue, thin-bedded; weathers light blue, tiny fossils or concretions	25
Total unit B	85
A. Conglomerate unit: Upper 20 feet consists of sandstone pebble conglomerate having rounded pebbles of coarse-grained sandstone mostly less than 1 inch in diameter in a matrix of angular white quartz grains. Beds are thick and lenticular. The remainder consists of limestone pebble and cobble conglomerate having coarse detritus composed mostly of bluish-gray-weathered limestone but also of some green limestone and rarely red sandstone, and being cemented with finely clastic blue-weathered limestone. Pebbles and cobbles are rounded to subangular and vary in size from less than 1 inch to 1 foot. Beds average 15 feet in thickness, are poorly defined, and show occasional graded bedding. Some fossil wood is present.	
5. Sandstone conglomerate, coarse-grained; rounded sandstone pebbles mostly 1 inch or less in size; matrix composed of white angular grains; thick-bedded, lenticular; lacks fossils	20
4. Limestone conglomerate, same type as unit 2	189
3. Limestone conglomerate, same type as unit 2, yellowish chert horizon	15
2. Limestone conglomerate; principally unsorted boulders, mostly rounded and subangular, some angular; boulders mostly blue limestone, some green limestone, rarely red sandstone, cemented by fine-grained blue limestone; detritus varies from less than an inch to 1 foot, occasionally graded; beds approximately 15 feet thick; lacks fossils	160
Total unit A	384
Total Hell-to-Finish Formation measured	769
Erosional unconformity.	
Earp Formation:	
1. Predominant lithology is of brown-weathered, calcareous, thinly cross laminated siltstone interbedded with poorly consolidated gray claystone; weathers buff; one bed of silty limestone, fine-grained, greenish-gray to pink on fresh surface, thin-bedded, few inches thick; essentially unfossiliferous (some plant fragments); remarkably uniform lithology over entire section	612
Disconformity.	
Horquilla Limestone.	

BENNETT CREEK SECTION

The Bennett Creek section, which includes the lower part of the Mojado Formation, was measured by Alper in sec. 2, T. 31 S., R. 18 W. Description of the section follows:

	Thickness (feet)
Bennett Creek Breccia.	
Angular unconformity.	
Mojado Formation:	
36. Sandstone conglomerate, round sandstone pebbles less than 1 inch in diameter; lenticular body	11

		Thickness (feet)
35.	Sandy shale, green, thin-bedded, friable; blocky fracture; interbedded with sandstone, medium-grained, white, friable	46
34.	Fossiliferous limestone, medium- to coarse-grained, brown with blue fossils, lenticular; weathers brown; pelecypods and gastropods	3
33.	Sandstone, cream, quartz sand firmly cemented with calcite, cross-bedded; weathers orange	11
32.	Sandy shale; green, friable; interbedded with sandstone, cream, friable	140
31.	Sandstone, cream, limonite-stained, well-indurated; weathers orange	32
30.	Sandy shale, medium-grained, thin-bedded, friable; plant fossils	44
29.	Covered by alluvium. Probably underlain by interbedded sandstone and green sandy shale	516
28.	Sandstone, medium-grained, white, friable	18
27.	Sandstone, medium-grained, cream, 3- to 6-foot beds, well-indurated; weathers orange-pink	58
26.	Sandy shale, fine-grained, green, 2- to 3-inch beds, friable, badly fractured; plant fossils	13
25.	Sandstone and green sandy shale interbedded; largely covered by alluvium	55
24.	Sandstone, white with orange limonite specks; weathers with manganese and limonite stains, partly covered by alluvium	80
23.	Sandstone, cream, quartz sand firmly cemented with calcite, cross-bedded; weathers orange-pink	9.5
22.	Calcareous sandstone, coarse-grained, blue with green specks; uranium check negative	11
21.	Sandstone, cream, well-indurated, cross-bedded; weathers orange	27.5
20.	Limestone conglomerate made up of small limestone pebbles; lenticular beds averaging 4 feet thick, 18 feet long	4
19.	Sandy shale, green, friable, thin-bedded	4.5
18.	Sandstone, white, friable; breaks into angular fragments	9
17.	Sandstone, cream, quartz sand firmly cemented with calcite, cross-bedded; weathers orange	56
16.	Sandy shale, green, friable, lenticular	12
15.	Sandstone, medium-grained, cream, quartz sand firmly cemented with calcite, bedded; weathers brown	20
14.	Concealed by alluvium. Probably underlain with friable green sandy shale interbedded with white sandstone	82
13.	Sandstone, medium-grained, cream, well-indurated; weathers orange	7
12.	Sandstone, manganiferous, black-brown	15
11.	Sandstone, medium-grained, white, well-indurated, cross-bedded; weathers orange; ridge-former	56
10.	Sandy shale, medium-grained, green-orange, friable; breaks up into blocky ¼-inch fragments	8
9.	Sandstone, medium-grained, white, thick-bedded, well-indurated, cross-bedded; weathers orange-pink; ridge-former	28
8.	Sandstone, medium-grained; interbedded green sandy shale and white sandstone, friable, nonresistant; largely covered by alluvium	200
7.	Sandstone, medium-grained, white with orange limonite specks, cross-bedded, 4- to 6-foot beds; weathers orange and pink; ridge-former	56
6.	Sandstone, medium-grained, white, 3-ft. beds, well-indurated; weathers yellow-white; forms 3-ft. angular blocks upon weathering	24
5.	Sandy shale, medium-grained, green, friable	6

	Thickness (feet)
4. Sandstone, medium-grained, cream, quartz, well-indurated; weathers brown-orange	1.5
3. Limestone conglomerate lens, fine-grained; blue, light blue, and cream pebbles ¼ to ½ inch in diameter	2.5
2. Sandstone, medium-grained, cream, well-indurated	14
1. Sandy shale, medium-grained, green; argillaceous matrix; blocky fracture	8
Total Mojado Formation measured	1688.5

U-Bar Formation:

Massive limestone.

UPPER PART OF BLUFF CREEK FORMATION

This section is in the S¼ sec. 6, T. 32 S., R. 17 W.

	Estimated Thickness (feet)
Gillespie Tuff.	
Upper part of Bluff Creek Formation:	
18. Agglomerate, pink, indurated; quartz, feldspar, and biotite crystals; sandstone fragments	100
17. Agglomerate, pink, some Cretaceous limestone boulders	20
16. Tuff, pink, well-indurated	30
15. Tuff, pinkish-white, soft, biotite crystals	10
14. Sandstone, pink, andesite fragments and boulders	3
13. Conglomerate, cream	25
12. Tuff, purple, well-indurated, quartz and feldspar crystals	50
11. Tuff, pink, soft; feldspar, quartz, and biotite crystals; angular fragments	30
10. Sandstone, brown	5
9. Volcanic breccia, white to pink, angular fragments	20
8. Tuff, white, indurated, quartz and feldspar crystals	60
7. Tuff, purple, indurated, potash feldspar and plagioclase crystals	15
6. Tuff, white	50
5. Tuff, pink, indurated; quartz, feldspar and biotite crystals	40
4. Tuffaceous agglomerate; purple; crystals of quartz, biotite, and feldspar; subangular fragments	35
3. Tuff, white, soft	20
2. Sandstone, green, well-indurated	10
1. Tuff, purple, lacking megascopic crystals	60
Total estimated thickness of upper part of Bluff Creek Formation	583
Alluvium.	

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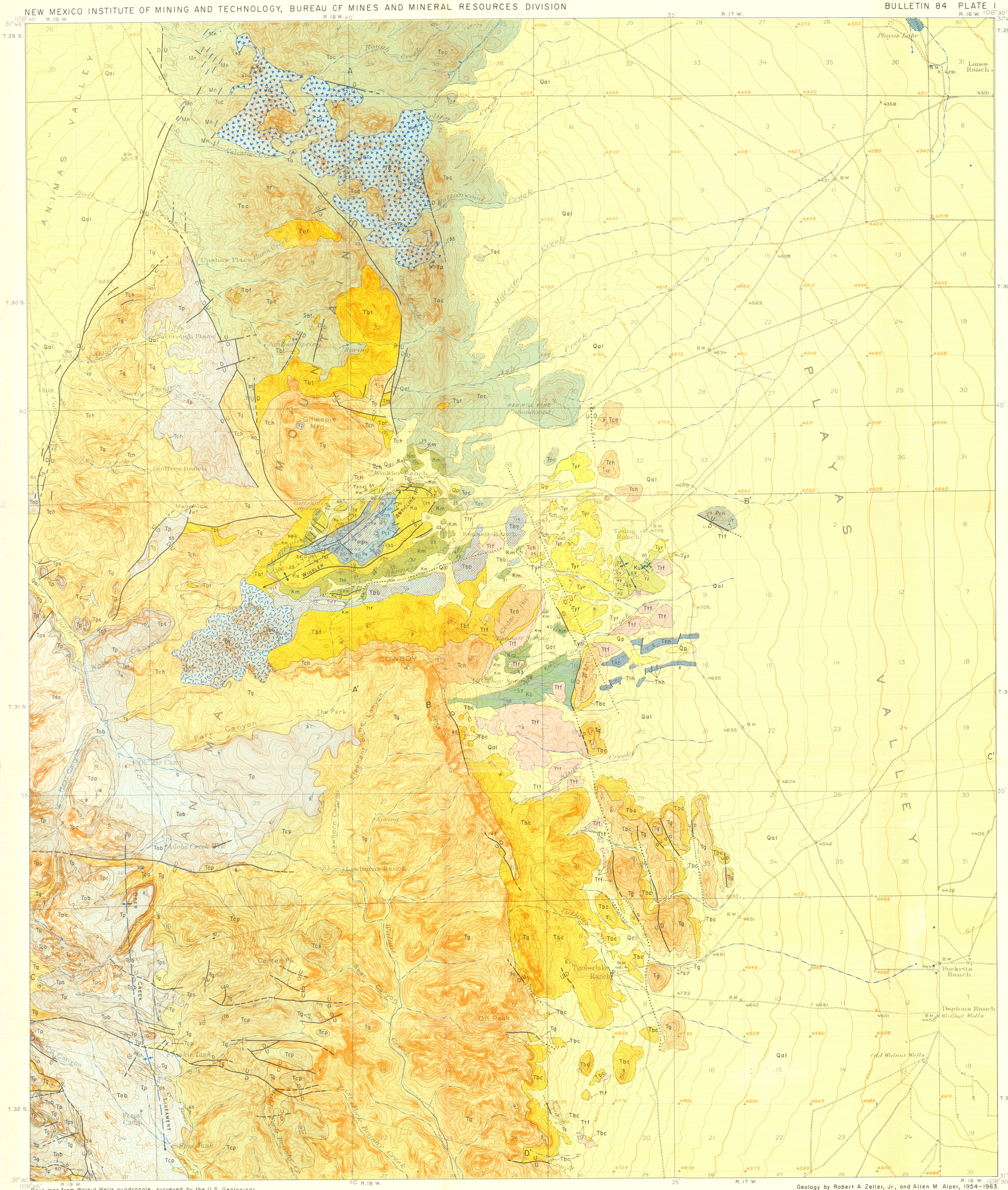
Index

Numbers in **boldface** indicate main sections

NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY, BUREAU OF MINES AND MINERAL RESOURCES DIVISION

BULLETIN 84 PLATE I



Base map from Walnut Wells quadrangle; surveyed by the U.S. Geological Survey in cooperation with the War Department, 1917–1918.

Geology by Robert A. Zeller, Jr., and Allen M. Alper, 1954–1963.
Geologic cartography by W.E. Arnold and Lola M. White.

GEOLOGIC MAP OF THE WALNUT WELLS QUADRANGLE, NEW MEXICO

Scale 1:48,000

1 0 1 2 3 4 Miles

Contour interval 25 feet Datum is mean sea level

EXPLANATION

QUATERNARY

Qal
Alluvium
Valley and canyon fill, arroyo deposits, and talus in the mountains. Alluvial fan, arroyo, and lacustrine deposits in Animas and Playas Valleys

EROSIONAL UNCONFORMITY

Qp
Pediment gravel
Elevated and dissected unconsolidated gravel and cobble beds resting on pediment surface

ANGULAR UNCONFORMITY

TERTIARY

Toa
Intrusive olivine andesite

Tql
Quartz latite dikes
Quartz latite porphyry

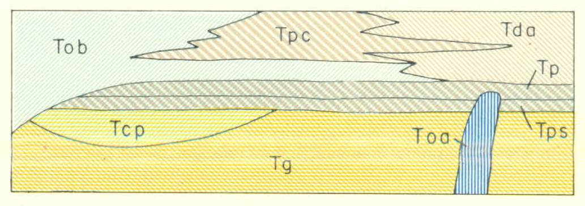
Tpc
Pine Canyon Formation
Latite porphyry flow rock

Tda
Double Adobe Latite
Coarsely crystalline latite porphyry flow rock

Tob
OK Bar Conglomerate
Pebble and cobble conglomerate composed of volcanic detritus; local beds of sandstone and of sedimentary breccia

EROSIONAL UNCONFORMITY

Tp / Tps
Park Tuff
Tp – Widespread sheet of welded crystalline rhyolite tuff
Tps – Basal sandstone member



Diagrammatic cross section of Tertiary formations in southwestern quarter of area

EROSIONAL UNCONFORMITY

Tcp
Center Peak Latite
Hornblende latite porphyry flow rock

EROSIONAL UNCONFORMITY

Tg
Gillespie Tuff
Massive coarsely crystalline welded tuff of quartz latite composition

Tbc
Bluff Creek Formation
Quartz-latitic pyroclastic rocks interbedded with lenticular beds of tuffaceous sandstone and shale

Tyr
Young Ranch Tuff
Crystalline quartz latite tuff; local sandstone and limestone at base

DISCONFORMITY

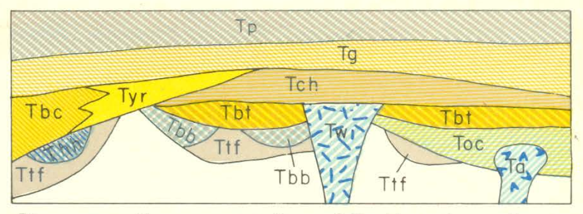
Tch
Cedar Hill Andesite
Andesite porphyry flow rock

EROSIONAL UNCONFORMITY

Tw
Walnut Wells Monzonite
Monzonite porphyry of the Walnut Wells plug

Ta
Animas Quartz Monzonite
Quartz monzonite porphyry of the Animas stock

Tbt
Basin Creek Tuff
Crystalline tuff, tuff breccia, and tuff agglomerate of quartz latite composition



Diagrammatic cross section of Tertiary formations in northern two-thirds of area

Toc
Oak Creek Tuff
Massive crystalline quartz latite tuff with basal zone of agglomerate and breccia

Thh
Horse Hill Breccia
Heterogeneous pyroclastic breccia of rhyolite composition

Tbb
Bennett Creek Breccia
Angular fragments of volcanic and sedimentary rocks embedded in tuff of quartz latite composition

Ttf
Timberlake Fanglomerate
Fanglomerate composed largely of limestone cobbles and of limestone-cobble-conglomerate boulders derived from erosion of the Cowboy Spring Formation

ANGULAR UNCONFORMITY

LOWER OR UPPER CRETACEOUS

Kc
Cowboy Spring Formation
Limestone-cobble conglomerate interbedded with red shale

LOWER CRETACEOUS

Km
Mojado Formation
Brown-weathered sandstone with interbedded shale

Ku
U-Bar Formation
Thin-bedded fossiliferous limestone interbedded with shale and sandstone; massive limestone reef at top. Conglomerate and red beds at base belong to the Hell-to-Finish Formation, which is included here with the U-Bar Formation for geologic mapping

EROSIONAL UNCONFORMITY

PERMIAN

Pch
Concha Limestone
Medium-bedded bioclastic limestone with abundant chert nodules and silicified brachiopods

Ped
Epitaph Dolomite
(Epitaph Dolomite and Scherrer Formation are not exposed in this area. Epitaph Dolomite is shown in the geologic section.)

Pcl
Colina Limestone
Medium-bedded finely crystalline limestone that is black on fresh surfaces and medium to light gray on weathered surfaces; only a few fossils are present

Pe
Earp Formation
Brown-weathered thinly crosslaminated siltstone interbedded with light gray clay and shale

DISCONFORMITY

PERMIAN AND PENNSYLVANIAN

PPh
Horquilla Limestone
Medium-bedded and massive bioclastic limestone containing fusulinids; some beds have chert nodules

?
Contact
Dashed where approximately located. Question mark indicates doubtful or probable contact

U D 47 ?
Fault, showing dip
Dashed where approximately located; dotted where concealed. Question mark indicates doubtful or probable fault. U, upthrown side; D, downthrown side

Anticline
Showing trace of axial plane and direction of plunge of axis; dashed where approximately located

Syncline
Showing trace of axial plane and direction of plunge of axis; dashed where approximately located

12
Strike and dip of beds and layers

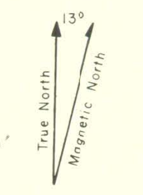
⊕
Horizontal beds

6
Strike and dip of planar flow structure

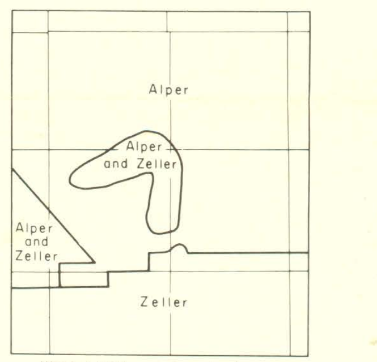
10
Bearing and plunge of lineation

⚒ Mine × Prospect

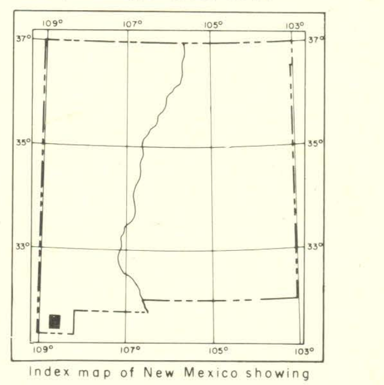
Mn
Manganese veins



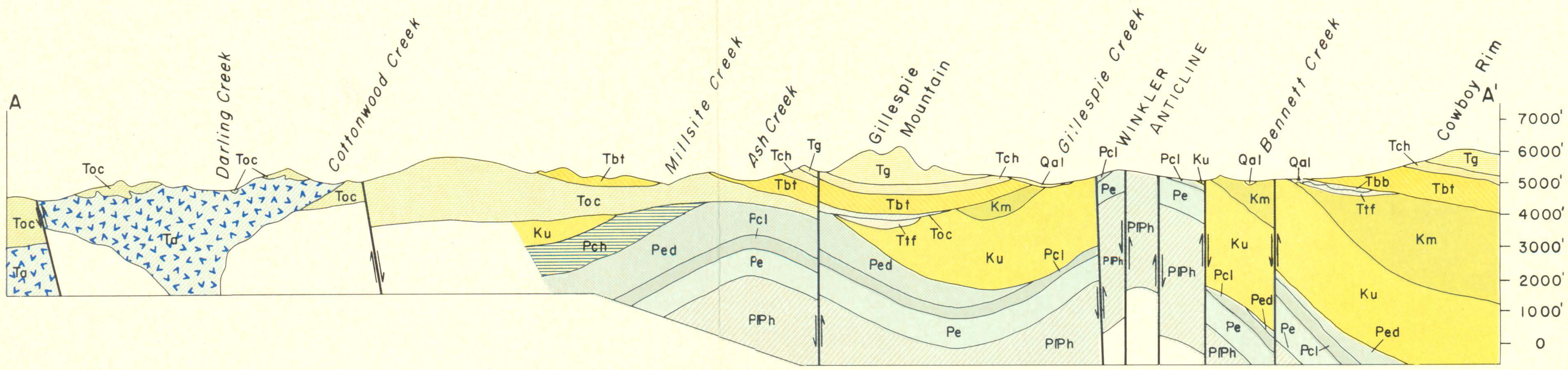
Approximate mean declination 1959

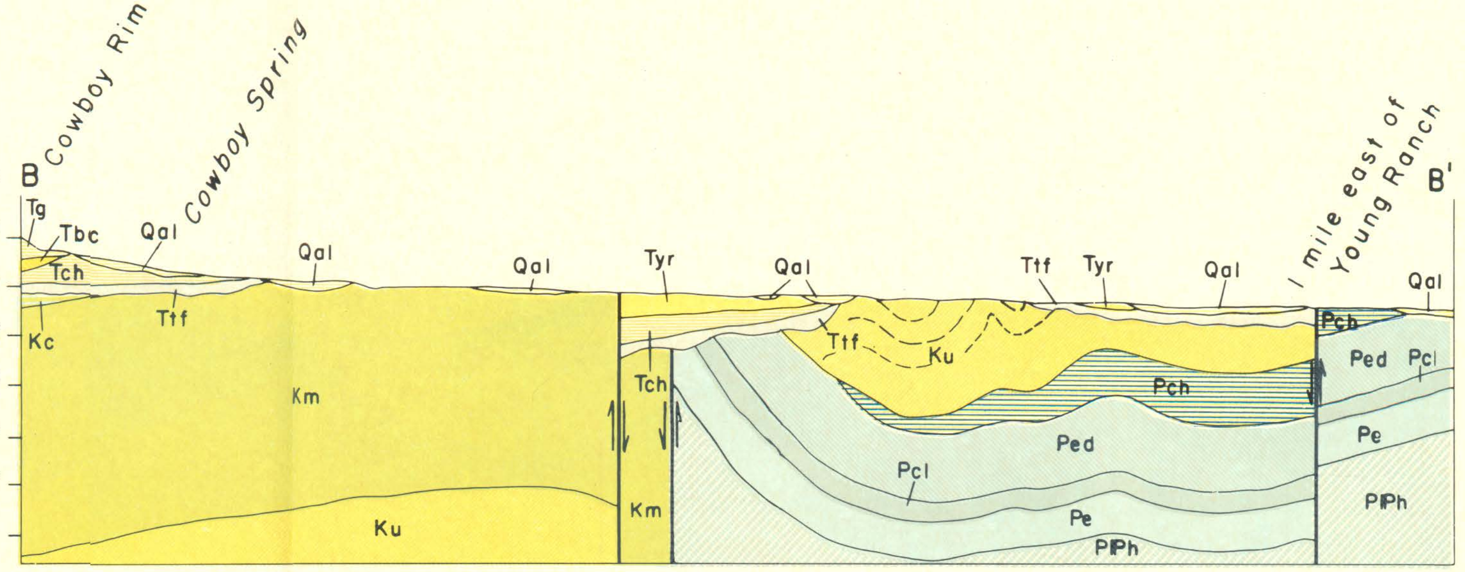


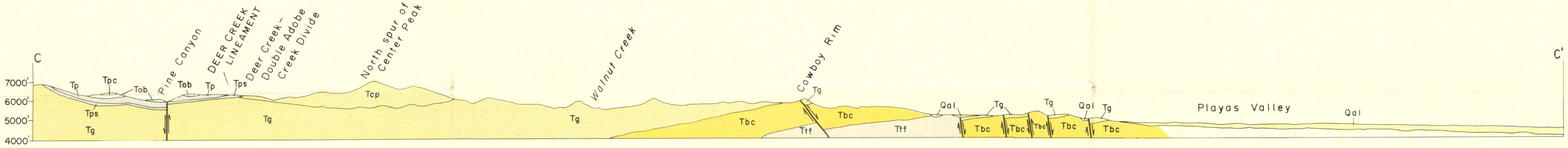
Walnut Wells quadrangle showing parts mapped by each author

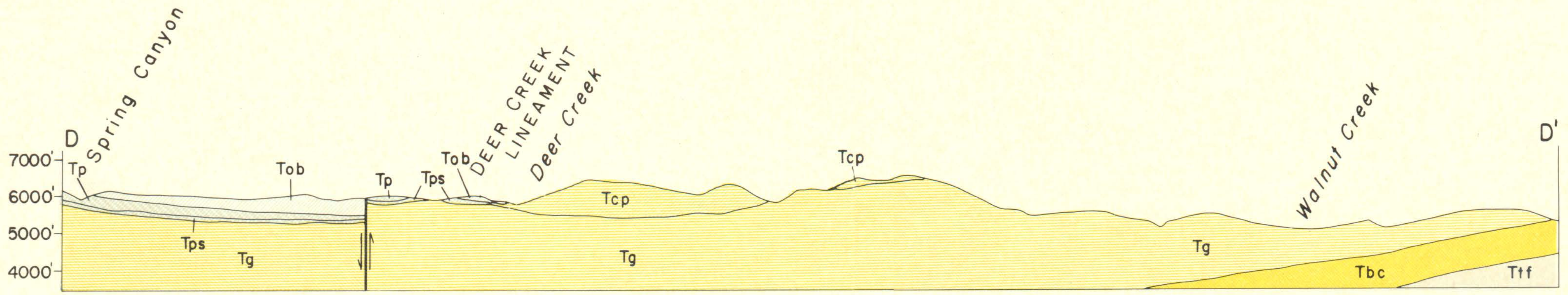


Index map of New Mexico showing location of Walnut Wells quadrangle









Note: See Plate I for explanation and location of geologic sections. Epitaph Dolomite (Ped) shown in geologic sections does not crop out in quadrangle. High angle faults of uncertain dip direction are arbitrarily shown as vertical.

Geology by Robert A. Zeller, Jr., and Allen M. Alper, 1954–1963. Geologic cartography by W. E. Arnold and Lola M. White

GEOLOGIC SECTIONS OF THE WALNUT WELLS QUADRANGLE, NEW MEXICO

1 0 1 2 3 4 Miles

Vertical scale = Horizontal scale